NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AN ASSESSMENT, SURVEY, AND SYSTEMS ENGINEERING DESIGN OF INFORMATION SHARING AND DISCOVERY SYSTEMS IN A NETWORK-CENTRIC ENVIRONMENT

by

Kristine M. De Soto

December 2009

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2009	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE An Assessment, Survey, and Systems Engineering Design of Information Sharing and Discovery Systems in a Network-Centric Environment			**5. FUNDING NUMBERS**
6. AUTHOR(S) Kristine M. De Soto			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Information, and the knowledge gained from it, has been the key component to strategic planning since the earliest combat operations. Success in the Information Age is defined by the military's ability to communicate effectively in a dynamic environment and share relevant information seamlessly. Sharing information is a critical element to understanding missions that employ the operational concept of Network-Centric Operations and Warfare (NCOW). Discovering valuable information is vital towards our capacity to predict and/or prevent circumstances in our current war against terrorist organizations.

This thesis describes fundamental concepts of information sharing and information discovery. Through the use of a systems engineering approach, this thesis created a common vision of an information sharing and discovery (ISD) system, evaluates the role of ISD in network-centric systems (NCS), and discusses the relationship of NCS to NCOW. This study also employs the system architecture method to establish the operational concept of ISD systems; derive requirements for future acquisitions of ISD systems; analyze the interactions that ISD systems have with external systems; and establish a functional architecture for the ISD system.

This research approach provides guidance for the development and integration of future ISD systems in order to meet the needs of future DoD NCS.

14. SUBJECT TERMS Systems Engineering, Systems Architecture, Network-Centric Systems, Network-Centric Warfare, NCW, Network-Centric Operations, NCO, Information Sharing, Information Discovery			**15. NUMBER OF PAGES** 129
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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AN ASSESSMENT, SURVEY, AND SYSTEMS ENGINEERING DESIGN OF INFORMATION SHARING AND DISCOVERY SYSTEMS IN A NETWORK-CENTRIC ENVIRONMENT

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

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ABSTRACT

Information, and the knowledge gained from it, has been the key component to strategic planning since the earliest combat operations. Success in the Information Age is defined by the military's ability to communicate effectively in a dynamic environment and share relevant information seamlessly. Sharing information is a critical element to understanding missions that employ the operational concept of Network-Centric Operations and Warfare (NCOW). Discovering valuable information is vital towards our capacity to predict and/or prevent circumstances in our current war against terrorist organizations.

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EXECUTIVE SUMMARY

Since the time of the earliest war strategists, information—and the knowledge gained from it—has been the key component to successful military planning in combat operations. Today's military professional still requires credible information in a very dynamic environment, and is also required to collaborate with counterparts distributed throughout the world. To be successful, our military must be able to communicate effectively and share relevant information seamlessly. This is not a simple task in today's national defense environment. Success in the Information Age is defined by the Department of Defense's (DoD) ability to adapt to changes due to the latest information technologies before our adversaries. To meet the unique challenges the Information Age presents the DoD is employing systems that are able to collect and present critical information to end-users efficiently. These systems—information sharing and discovery (ISD) systems—are crucial to military operations because our strategic plans are only as good as the information that it is composed of. The sharing of quality information is an especially important element in determining the success of missions that employ Network-Centric Operations (NCO) and Network-Centric Warfare (NCW) (Alberts, Garstka, and Stein 1999, 7). Discovering valuable information is vital towards our capacity to predict and/or prevent circumstances in our current war against terrorist organizations.

In spite of the importance of information sharing and discovery, there is currently no specific guidance that identifies what ISD systems entail. There is an absence of basic elements of the systems engineering approach and design for ISD systems, such as: an operational concept; requirements; interface guidance; and functional architecture. Terms, definitions, and key concepts about the important elements of information sharing and information discovery are also lacking (and those that exist are not standardized); so, it is often hard for a user to understand what his or her service (i.e., information) can offer them. Furthermore, it is even more difficult for DoD acquisition professionals to acquire or develop ISD systems because of the mixing of DoD and industry terms and perceptions, and lack of systems design requirements.

This thesis assesses current ISD systems used in the DoD and surveys relevant commercial industry trends that may be useful in the military network-centric environment. A systems engineering approach is applied to determine what today's military requires from information sharing and discovery systems to be valuable to Network-Centric Operations and Warfare (NCOW) and the varying mission sets of the military. The goal was to better understand the concept of an ISD system and introduce a generalized design for ISD systems that considers functions necessary for future military endeavors.

To conduct this study, this thesis first presented a brief summary of the history of Network Centric Operations and the Network Centric Warfare model and its applications to current military doctrine. These concepts are summarized to show the importance of information sharing and information discovery to ongoing military strategic planning and to introduce the concept of "information superiority" as it applies to current military strategy. The concepts of the global information grid and net-centricity were also explored to highlight the role of information sharing and information discovery in network-centric systems.

Next, an overview of ISD systems was given to explain the importance of information sharing and information discovery and to define these terms as the basis of this study. Information sharing and the recent attention this term has gained in recent years was discussed to give the audience background information and a context for this term. A discussion of the four core approaches for a network-centric system and their independent functions was explained to show how ISD systems are valuable to the network-centric environment. A general model illustrating how information sharing leads to information discovery showed that ISD systems reside in the top-down approach.

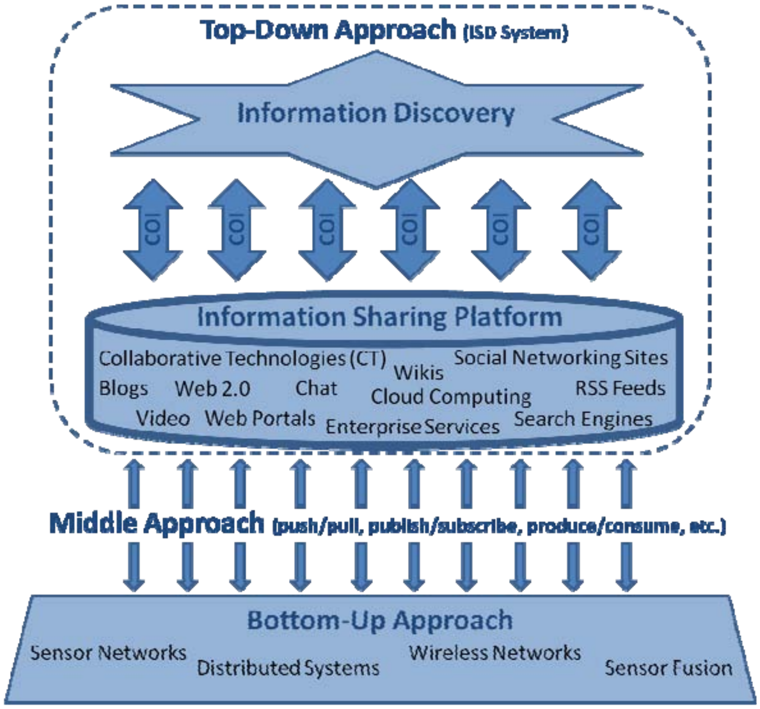

Figure 1. Information Sharing leads to Information Discovery

Additionally, a wide array of current DoD system implementations was examined and discussed to give the audience examples of current tools and services that are available to warfighters. Upcoming industry trends were discussed to highlight the potential of future information sharing and discovery capabilities.

Following the survey of NCOW's history and the introduction of the operational concept of the ISD system, the thesis progressed through the system architectural methodology presented by Buede (Buede 2000, 20). The methodology begins with the refinement of the operational concept of the ISD system that was introduced in previous chapters.

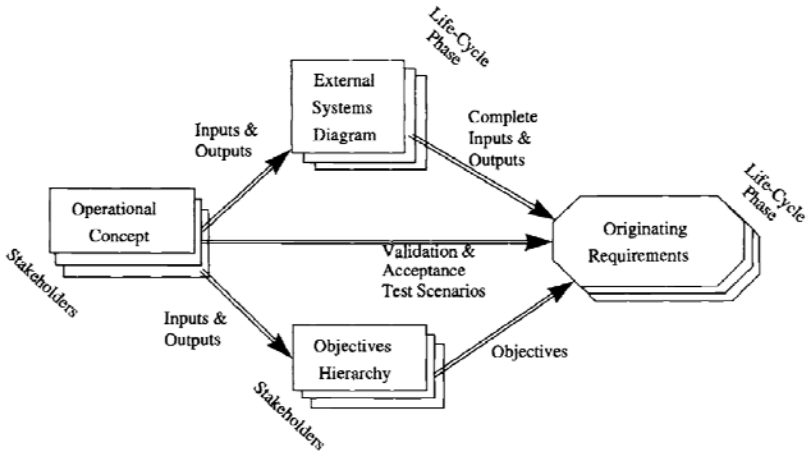

Figure 2. Summary of originating requirements development (From Buede 1999, 159)

An external system diagram for the ISD system was created to introduce the external systems that the ISD system must interface with. The external system diagram helped to bound the system design problem. Interactions between the ISD system and its external systems were traced to highlight the interface between the ISD system and other systems.

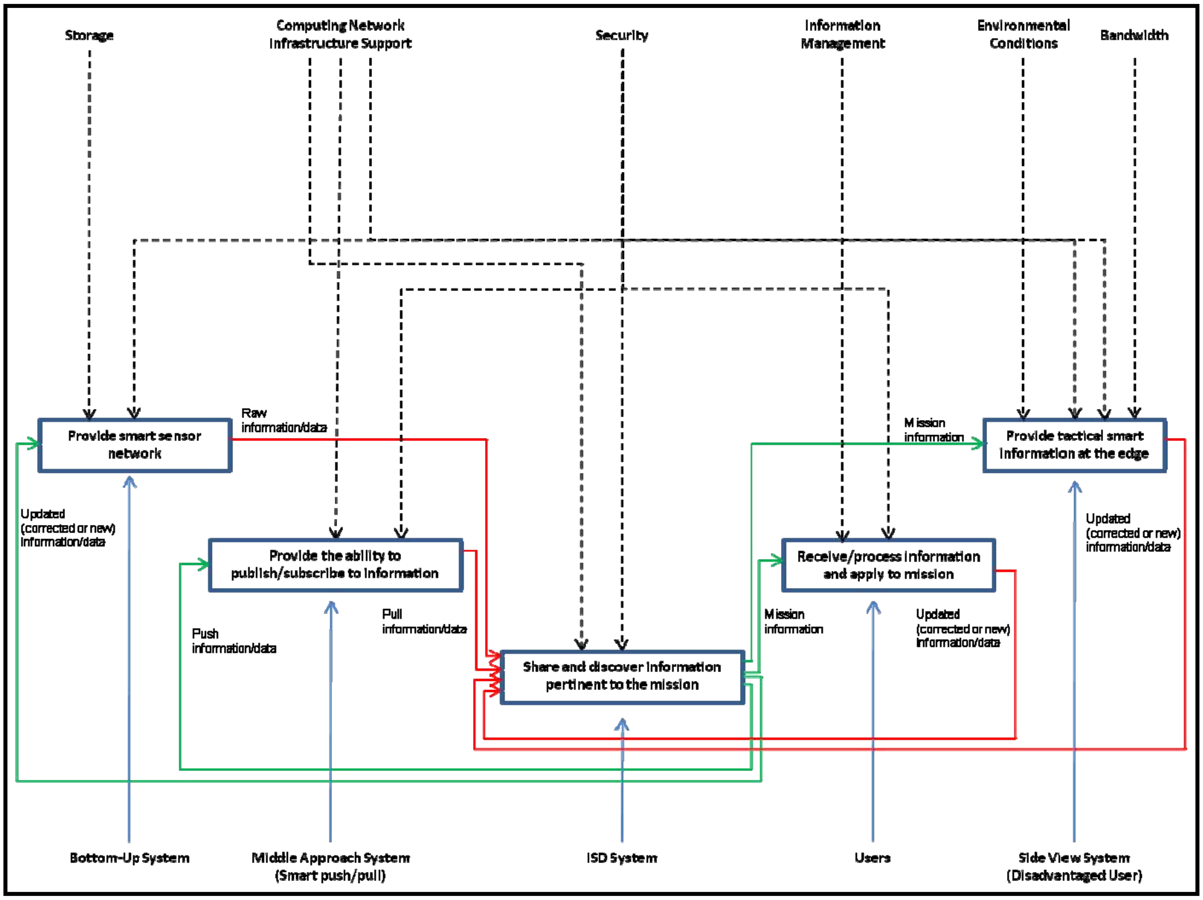

Figure 3. ISD System External Systems Diagram

Next, the concept of the systems objective hierarchy addressed fundamental objectives for the ISD system. Finally, a summary of the different types of requirements categories was introduced and generalized requirements for future ISD systems were established.

Following the introduction of ISD system requirements, the following chapter further designed the ISD system and presented key products created in the process of developing a functional architecture for the ISD system. The functions for the ISD system were identified and presented in the system functional hierarchy.

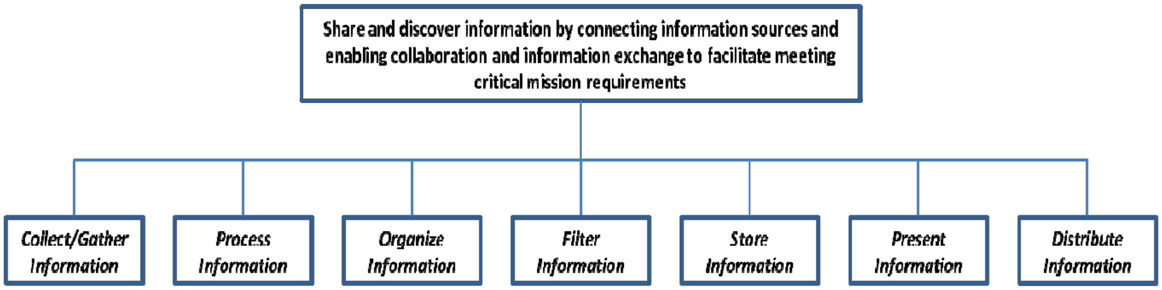

Figure 4. Top-level ISD System Functions

Functional decompositions of each of the ISD system's seven top-level functions was conducted. Finally, several requirement traceability matrices were introduced to track requirements to elements of the ISD system's functional architecture.

This thesis provides a top-level view of information sharing and discovery systems, which will enable future acquirers to be familiar with information sharing and discovery requirements. This study will allow DoD acquisition professionals to make informed decisions about future network-centric systems and their information sharing and discovery elements. It will also familiarize network-centric system users with the tools they are equipped with and allow them to understand which functional features of ISD systems are useful to their current operations.

This thesis, its systems engineering approach, and its conclusions, provide numerous areas of potential study and can assist in the development and integration of future ISD systems for use in network-centric systems, and in the needs of future military forces.

ACKNOWLEDGMENTS

Thank you to professor Shebalin for your assistance in organizing and forming the content of this thesis.

Many thanks, also, to professor Goshorn for your guidance and mentoring during the research and writing of this thesis. Your belief in my abilities enabled me to write this thesis confidently.

Finally, my sincerest thanks to my family for your continued love, support, and encouragement through the course of my naval career. This thesis is as much your work as it is mine.

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I. INTRODUCTION

In your thirst for knowledge, be sure not to drown in all the information.
– Anthony J. D'Angelo (The College Blue Book)

This chapter introduces background information about the important role that information plays in today's military environment and discusses the need for information sharing and discovery systems. The author's personal motivation behind choosing this particular research subject is provided. The purpose of the study and the research questions that were undertaken are also introduced. The scope and methodology of the research is outlined to aid in the organization of the thesis.

A. BACKGROUND

Since the time of the earliest war strategists, information—and the knowledge gained from it—has been the key component to successful military planning and operations. Circumstances in our present military are not very different. We still recognize the value of credible information, however, today's military professional is now required to collaborate with counterparts distributed throughout the world and is expected to keep abreast of a very dynamic environment. To be successful, our military must be able to communicate effectively and share relevant information seamlessly. This is not a simple task in today's national defense environment. The Information Age is the period following the Industrial Age which has been defined by widespread access to information primarily due to information technology (United States Department of Defense Office of Force Transformation 2005). It has introduced an entirely new set of conditions that must be met in order to remain competitive against our adversaries. To meet the unique challenges the Information Age presents, the Department of Defense (DoD), and industry alike, is employing systems that are able to collect and present critical information to end-users efficiently. These systems—information sharing and discovery (ISD) systems—are crucial to military operations because our strategic plans are only as good as the information that it is composed of. The sharing of quality

information is an especially important element in determining the success of missions that employ Network-Centric Operations (NCO) and Network-Centric Warfare (NCW) (Alberts, Garstka, and Stein 1999, 7).

In spite of the importance of information sharing and discovery, the problem exists in which there is currently no specific guidance that identifies what ISD systems entail. There is an absence of basic elements of the systems engineering approach and design for ISD systems, such as: an operational concept; requirements; interface guidance; and functional architecture. Terms, definitions, and key concepts about the important elements of information sharing and information discovery are also lacking (and those that exist are not standardized); so, it is often hard for a user to understand what his or her service (i.e., information) can offer them. Furthermore, it is even more difficult for DoD acquisition professionals to acquire or develop ISD systems because of the mixing of DoD and industry terms and perceptions, and lack of systems design requirements.

This thesis assesses current ISD systems used in the DoD and surveys relevant commercial industry trends that may be useful in the military environment. This study also discusses the need for ISD systems to support operations in a network-centric environment. Finally, this thesis uses a systems engineering approach to introduce the design of an ISD system for use as guidance in future development and acquisition.

B. PERSONAL MOTIVATION

In late 2005, I was working as an action officer in the Current Operations (N31) shop of the Commander, U.S. Pacific Fleet (COMPACFLT). I had been in the job for almost six months at this point, and I was quickly learning the demands were great—especially since I was the only Lieutenant in the shop full of Commanders! A significant part of my job was to answer Requests for Information (RFIs) concerning surface operations in the Pacific fleet. These information requests varied in scope and I was assigned to find information, expeditiously, to answer the tasking of the directorate leaders. After some trial and error, and with some turnover from my predecessor, I was surprised to find that the easiest and fastest way for me to find the information was to use

a search engine, such as Google, as a starting point for information. I would "Google" a term or phrase relating to the inquiry and, depending on the results of the search; I would find other resources to examine. In the cases where it was a classified matter, I used search engines similar to Google on the classified Secret Internet Protocol Router Network (SIPRNet). Often, I would have information sources that conflicted directly with each other and would have to find a way to resolve the difference in information quickly. This entire process was very different from what I was taught in my previous billet as a naval nuclear propulsion engineer aboard a nuclear aircraft carrier. There, the bulk of our information came from a set of Reactor Plant Manuals (RPMs) and Steam Plant Manuals (SPMs). Changes to these references were rare, so watchstanders were very certain of the information from these manuals to guide our operations in the reactor plant. It highlighted a very large contrast, to go from very few sources of dependable information to an infinite source of references with varying assurances on the quality of information.

My biggest assignment during the COMPACFLT tour came in early 2006, when my shop was tasked with planning the USNS Mercy deployment as a follow-up to Operation Unified Assistance, the previous year's response to the Indian Ocean tsunami. This was a highly visible and wide-reaching project that required intense coordination with defense assets, as well as Non-Government Organizations (NGOs). Planning started almost a year prior to the deployment because this type of mission was unprecedented. The USNS Mercy, a hospital ship, had only been deployed during crisis situations—there had never been a humanitarian assistance mission of this scope, and that was built on multifaceted international partnerships (Roughead 2009).

When it was time to start coordinating with participants approximately six months prior to the deployment date, information was flowing, but not all participants were "in the loop." There were copious amounts of information, and it was all one could do to keep abreast of the deployment preparation issues that had to be resolved. I found myself wondering if there was a better way to handle the information amongst the group—the network—of deployment planners. I realized that information needed to be shared in an organized (though not necessarily formal) manner. Then, the pertinent and reliable

information, needed to be discovered and vetted to the right leadership so that decisions could be made and action could be taken to progress the planning.

Great things happened during the USNS Mercy 2006 deployment—it was an immense success, and the mission was even carried into the next year with a different naval platform. Many would ask: if the deployment went so well, why is there a need to improve information sharing among deployment planners? It is true that many military missions are planned under the same circumstances—most times the result is success, and sometimes there are severe lessons to be learned. In whichever camp one resides, I suggest that my lessons from the lack of an information sharing and discovery structure can be applied to the greater scheme, and a larger network. Information, and the knowledge gleaned from it, enables action to occur (Nissen 2006, 20). The Information Age is bittersweet because data is in abundance, but this does not mean that information is shared efficiently. Timely and reliable information is essential to successful operations, especially in the military profession. Therefore, it is essential that we identify the correct tools to share relevant information and distribute them to our warfighters. Our military success is dependent on getting the correct information before our adversaries.

C. PURPOSE OF THE STUDY

The purpose of this thesis is to apply a systems engineering approach to determine what today's military requires from information sharing and discovery systems to be valuable to Network-Centric Operations and Warfare (NCOW). This thesis introduces a generalized design for ISD systems and considers potential functions that will be necessary for future military endeavors. A wide array of current military system implementations is examined and discussed. ISD topics that are addressed include network communications, Web-enabled services, collaborative technologies, data management, information discovery, service-oriented architecture, enterprise services, and the evaluation process that is inherent in bringing these programs to the warfighter. To avoid too broad of a study, the thesis assumes that the audience understands the fundamentals of computer networking and communications, and specific technical details about network sensors and distributed systems is omitted.

This top-level view of information sharing and discovery systems allows future acquirers to be familiar with NCOW information sharing and discovery requirements. This study enables DoD acquisition professionals to make informed decisions about future network-centric systems and their information sharing and discovery elements. This thesis also familiarizes network-centric system users with the tools they are equipped with and allows them to understand which functional features of ISD systems are useful to their current operations.

D. RESEARCH QUESTIONS

This thesis addresses the following primary research question:

Primary question: What information sharing and discovery system elements do network-centric systems require to be valuable to the military missions of Network-Centric Warfare and Network-Centric Operations?

To be able to answer the primary research question, several supporting questions need to be addressed and answered. These include, but are not limited to, the following subsidiary questions.

Subsidiary questions:

1. What is information sharing and information discovery?
2. What are the generalized approaches to information sharing and information discovery?
3. Why are information sharing and discovery services essential to network-centric systems?
4. What are key concepts, terms, and definitions a person must know to understand information sharing and information discovery services?
5. What is NCOW? How is information sharing and information discovery defined and used in NCOW?

6. From a systems engineering approach, what are the requirements and necessary capabilities for information sharing and discovery in network-centric systems?

7. What services currently exist that enable information sharing and information discovery in network-centric systems?

8. What are the current industry trends for future technologies in information sharing and discovery services?

9. How can the DoD use emerging commercial industry trends to benefit their strategic mission?

10. What NCOW information sharing and discovery issues must the DoD address in order to remain competitive against U.S. adversaries?

11. What additional issues must be addressed to improve information sharing and information discovery in future network-centric systems?

12. How should information sharing and discovery requirements guide acquirers, developers, and users?

E. BENEFITS OF THE STUDY

This thesis evaluates information sharing and information discovery in network-centric systems and discusses the relationship of these systems to NCOW. This study applies a systems engineering approach to establish requirements and initial design elements for future information sharing and discovery systems. The objective of this research is to provide guidance for the acquisition of future network-centric systems and component development. This study will also be used to develop Network-Centric Systems Engineering (NCSE) course material at the Naval Postgraduate School (NPS).

F. SCOPE AND METHODOLOGY

Research was conducted to reveal the brief history of NCOW in the DoD and to understand how the concepts of NCOW have transpired and been adapted in the current military strategy. A comprehensive review of the literature on the role of information

sharing and information discovery in various applications was performed to ascertain the importance of these processes to DoD endeavors. Interviews were conducted to support research on NCOW at the Defense Systems Information Agency (DISA) Customer Partnership Conference 2009, held 21-24 April, in Anaheim, California. Current and developing DoD systems and Web-enabled information sharing and information discovery services were examined to determine if these systems will meet the requirements of NCOW. The systems engineering design process was applied to produce a general ISD system design that includes: a set of operational concepts; an external systems diagram; a systems objective hierarchy; system requirements; a functional architecture; functional decompositions; and a requirements traceability matrix.

G. ORGANIZATION OF THE THESIS

This thesis is broken into five chapters:

Chapter I discusses the background, motivation, purpose, research questions, benefits of the study, scope, and methodology of the thesis.

Chapter II reviews the brief history of Network Centric Operations and the Network Centric Warfare model and it's applications to current military doctrine. These concepts are summarized to highlight the importance of information sharing and information discovery to ongoing military strategic planning.

Chapter III introduces the concepts of information sharing and information discovery, and defines these terms as the basis of this study. A survey of DoD information sharing and discovery systems is conducted to give the audience examples of current services available to warfighters. This chapter also discusses emerging industry trends for ISD systems and assesses their applicability to the DoD.

Chapter IV uses a systems engineering approach to establish the operational concept of ISD systems and derive requirements for future acquisitions of ISD systems. This chapter also analyzes the interactions that ISD systems have with external systems, and discusses the importance of clear objectives during the conceptual phase.

Chapter V uses a systems engineering approach to establish a functional architecture for the ISD system. This chapter discusses the functions identified for the ISD system and presents the ISD system functional hierarchy.

Chapter VI concludes the thesis by summarizing key points made throughout the study. This chapter also suggests several areas to conduct further research about ISD systems.

II. NETWORK CENTRIC OPERATIONS AND WARFARE

Unless some type of network is created, sharing cannot occur.
– Dr. David S. Alberts

This chapter reviews the brief history of Network Centric Operations and the Network Centric Warfare model and their applications to current military doctrine. The main ideas of these concepts are summarized and discussed to highlight the importance of information sharing and information discovery to ongoing military strategic planning. The following sub-sections reveal how the Information Age has altered traditional military operations and discusses the concept of "information superiority" as it applies to current military strategy. This chapter also introduces the concept of the global information grid and net-centricity, and explains the role of information sharing and information discovery in network-centric systems.

A. FROM INDUSTRIAL AGE TO INFORMATION AGE

In 1996, the military was introduced to a new conceptual template called "full spectrum dominance" in the DoD publication, *Joint Vision* 2010 (United States Joint Chiefs of Staff 1995). The document, signed by then-Chairman of the Joint Chiefs of Staff Army General John M. Shalikashvili, defined full spectrum dominance as "the ability of US forces, operating unilaterally or in combination with multinational and interagency partners, to defeat any adversary and control any situation across the full range of military Operations"(United States Joint Chiefs of Staff 1995). Full spectrum dominance promoted a new theory of wartime dominance by advocating that the military focus on controlling all aspects of war, to include maritime space, air space, land forces, communications, and information contained within. This doctrine sought to create a template for how the DoD would "leverage technological opportunities" to conduct modern warfare.

A 1998 U.S. Naval Institute Proceedings journal article Vice Admiral Arthur K. Cebrowski and John Gartska, entitled *Network-Centric Warfare: Its Origin and Future* discussed the characteristics of a new warfare doctrine called Network Centric Warfare

(NCW). This article was subsequently followed by a book published in 1999 by David Alberts, John Gartska, and Frederick Stein entitled *Network Centric Warfare: Developing and Leveraging Information Superiority* (Alberts, Garstka, and Stein 1999, 1-4). NCW expanded on many of the concepts that were covered in Joint Vision 2010. In the book, the authors advocated a new way of thinking about the battlefield and about fighting wars in the Information Age. Admiral Jay Johnson, the former Chief of Naval Operations, called it "a fundamental shift from platform-centric warfare" because the authors discussed the shift from the Industrial Age warfare to the Information Age (Alberts, Garstka, and Stein 1999, 16–17). This was a critical revelation because the focus of Industrial Age military doctrine was set upon the fighting platform. In contrast to this, the authors contended that the Information Age advocated a network-centric way of thinking. The network-centric concept suggested that military platforms were no longer the focal point in military operations but a node in a very intricate global network.

Alberts, Garstka, and Stein suggested that adapting to the Information Age, and capitalizing on new information technologies (IT), could bring success to the U.S. military, as it had done with some commercial organizations. Figure 5 demonstrates the coevolution and shift to network-centric operations in commercial industry.

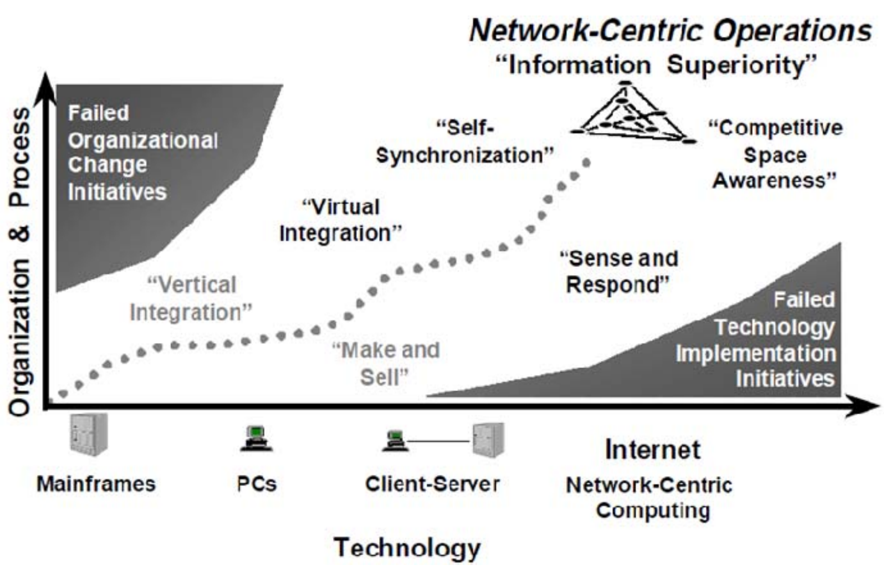

Figure 5. Coevolution and the Shift to Network-Centric Operations (From Alberts, Garstka, and Stein 1999, 28)

The authors analyzed the commercial sector to illustrate the potential the U.S. military had if they *also* capitalized on IT. Figure 5's x-axis represents organizational change and processes occurring in commercial industry. The y-axis corresponds to technological innovations that are currently occurring (i.e., the shift from mainframes computers to personal computing to client-server communications). Established companies, with a strong competitive advantage in the marketplace, follow the "trajectory of innovation" represented by the dotted line (Alberts, Garstka, and Stein 1999, 27-29).

As illustrated in Figure 5, the authors pointed out that the commercial industry was leading the way in the Information Age and that the military could learn from their example. Information technology and the move to leverage information to use to their advantage enabled strong companies to continue to succeed. Successful industry corporations embraced new technologies and also committed to the organizational change necessary to aid the new needs of consumers. The companies that did not adapt to the Information Age fast enough were failing and being driven out (or acquired) by their more successful competitors. Alberts, Cebrowski, and Gartska drew parallels from the commercial sector into military warfare doctrine and argued that NCW was the military's emerging theory of war in the Information Age (Alberts, Garstka, and Stein 1999, 25-27). In essence, the authors stated that NCW is the military's answer to the Information Age. How, though, would the U.S. military be able to gain a competitive advantage?

B. INFORMATION SUPERIORITY

The way that U.S. defense forces will be able to achieve success in future endeavors against adversaries is to achieve Information Superiority. Information Superiority is "…a state that is achieved when a competitive advantage is derived from the ability to exploit a superior information position" (Alberts, Garstka, and Stein 1999, 34) and is the basis that enables NCW to occur. It is a concept that depends on three characteristics of information: relevance, timeliness, and accuracy of the information presented.

As seen in Figure 6, the military (blue force) should strive to attain information that meet all three of the attributes (timeliness, accuracy, relevant information) and—at the same time—attempt to deny relevant information to adversaries (red force).

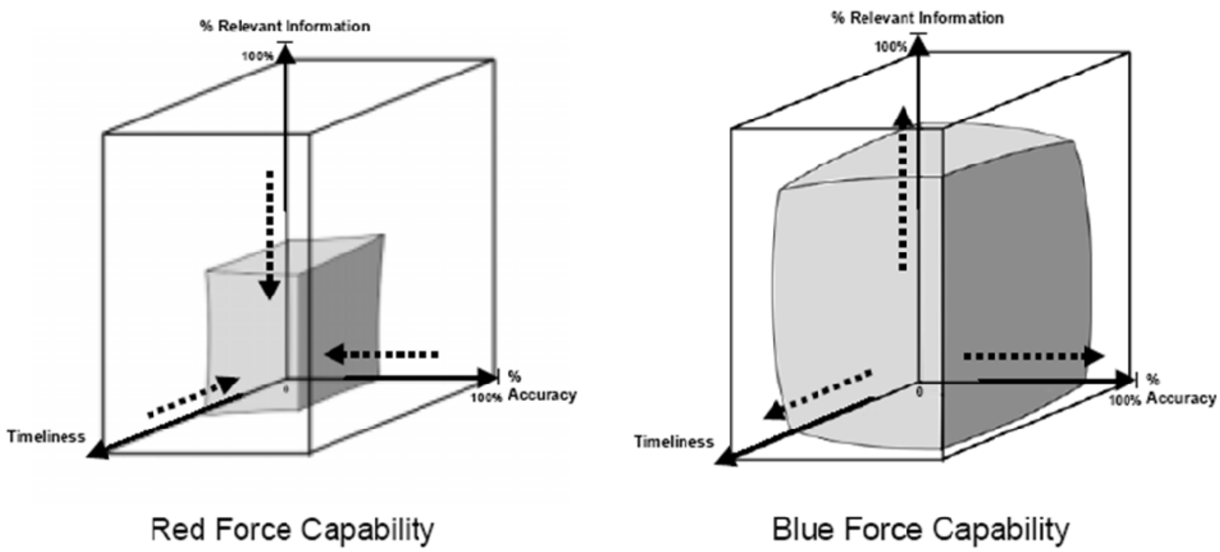

Figure 6. Superior Information Position Vis-À-Vis an Adversary (From Alberts, Garstka, and Stein 1999, 56)

Information superiority facilitates NCW and ensures combat power is achieved through (Alberts 2001):

- Increased Shared Awareness
- Increased Speed of Command
- Higher Tempo of Operations
- Greater Lethality
- Increased Survivability
- Streamlined Combat Support
- Effective Self-Synchronization

The notion behind information superiority, and the desire to attain it, is not a new wartime concept. The notion has been echoed by leaders throughout military history. In November 2003, for example, in *Joint Operations Concepts*, a United States Department of Defense, Director for Operational Plans and Joint Force Development document stated that "information superiority is an imbalance in one's favor in the information domain

with respect to an adversary. The power of superiority in the information domain mandates that the United States fight for it as a first priority even before hostilities begin" (United States Department of Defense, Director for Operational Plans and Joint Force Development).

The *incorporation* of the information superiority concept into the complex world we currently live in is, however, very new and very dynamic. The next step is to understand what tools are required to attain information superiority in the Information Age.

C. THE GLOBAL INFORMATION GRID

The network, and not the platform, is the focus of NCW. In the DoD the military network is referred to as the Global Information Grid, or more commonly, the GIG.

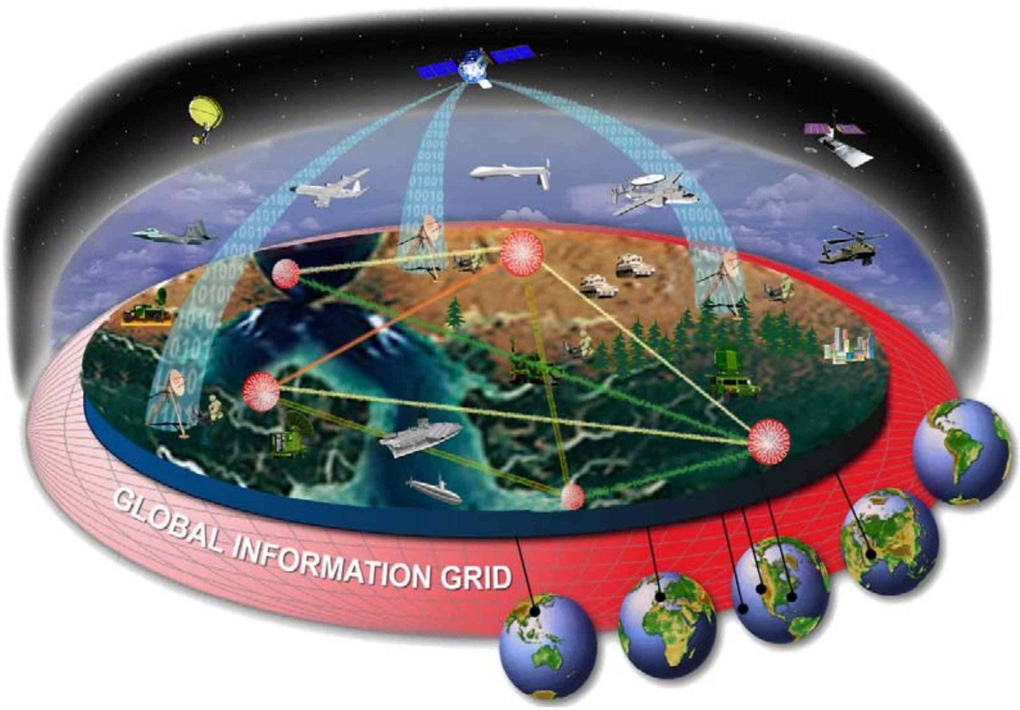

Figure 7. Global Information Grid (From Defense Information Systems Agency 2009)

The GIG defined as (Assistant Secretary of Defense for Networks and Information Integration/Department of Defense Chief Information Officer 2004):

> The globally connected, end-to-end set of information capabilities, associated processes, and personnel for collecting, processing, storing, disseminating, and managing information on demand to warfighters, policy makers, and support personnel

It is important to realize that the compilation of members, in the elaborate network that the GIG is comprised of, is more important than the individual components because interactions that occur between nodes are vital to the system. The synergy of network components enables the pursuit of Information Superiority to occur and achieve more than can be realized by individual elements. In other words, the well-known phrase “the whole is greater than the sum of the individual parts” certainly applies here. The GIG is the structure, which allows the DoD to communicate and share information relating to business, operations, and warfare.

The network and the Information Technology found within the GIG are fundamental to NCW, therefore it is important to realize that the power of the network is found within the nodes that are included in it. To further elaborate on this concept, Metcalf’s Law (Figure 8) explains that each node in network of “N” nodes is capable of initiating “N-1” interactions. As the number of nodes increases (y-axis), the power of the network also increases (y-axis).

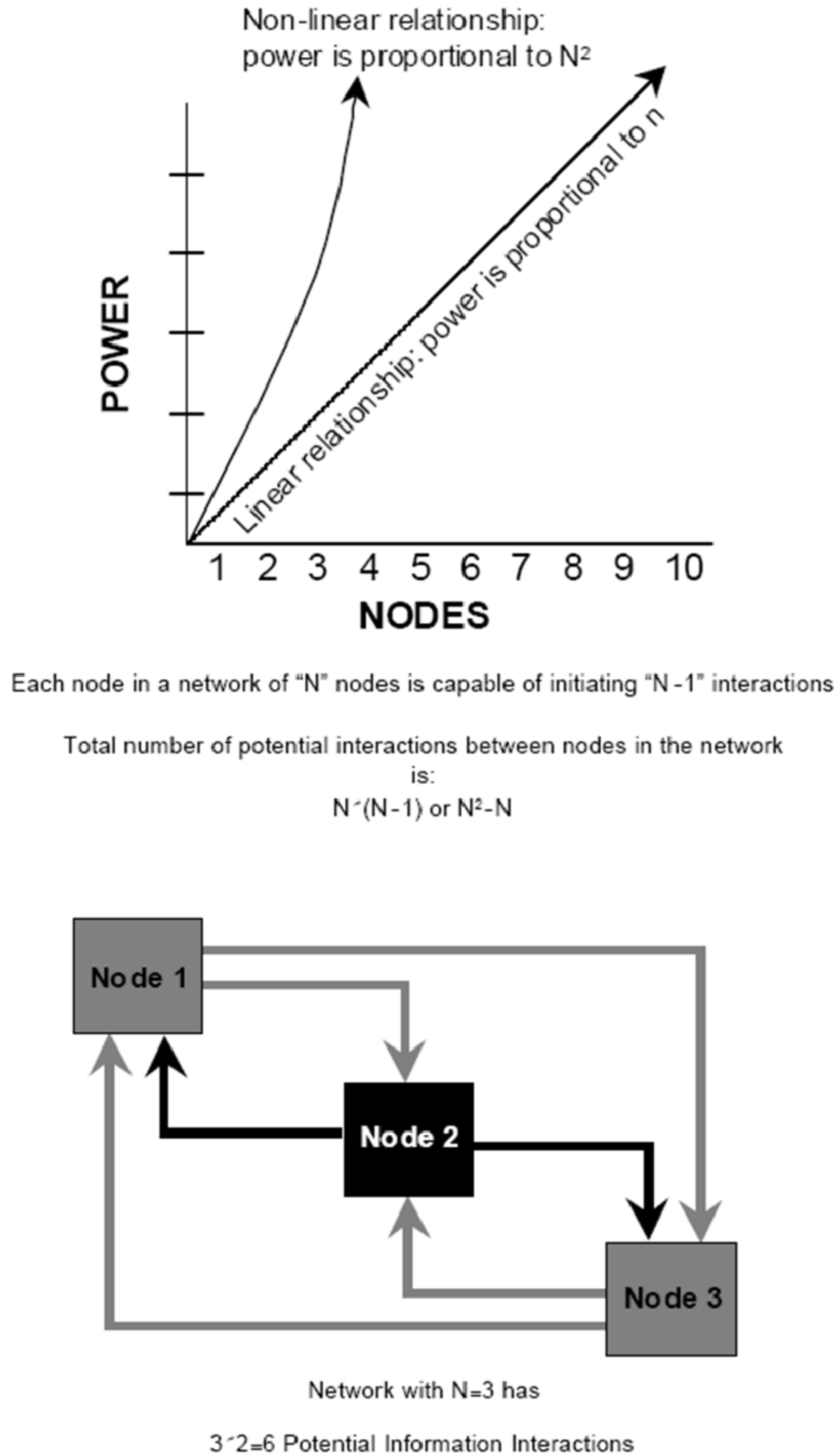

Figure 8. Metcalf's Law, Nodes vs Power (Top), Potential Information Interactions for N=3 nodes (Bottom) (From Alberts, Garstka, and Stein 1999, 33)

Therefore, the total number of (potential) interactions in a network is: $N*(N-1)$, or $N^2 - N$. "Although the cost of deploying a network increases linearly with the number of nodes in the network, the potential value of a network increases (scales) as a function of the square of the number of nodes that are connected by the network" (Alberts, Garstka, and Stein 1999, 32). Thus, the capabilities of the GIG depend upon the number of the nodes that are connected within it and the interactions that occur between nodes.

The GIG is continually evolving to increase the reach to entities that will be able to expand its capabilities by providing information. A powerful network is fundamental to Information Superiority because elements must be connected in order to contribute to the information fusion that creates the overall operation picture.

D. NET-CENTRICITY

The goal of the NCW and the GIG is to achieve a substantial DoD enterprise using Information Technologies. This network would be global, seamless, secure, and – most importantly—be available to warfighter when he or she needs it (Joyner 2005). The ultimate objective is to have ubiquitous access to information, so that users can access necessary information anywhere and at any time. This ambition is known as "net-centricity," and is defined as (Defense Information Systems Agency 2009):

> The realization of a robust, globally interconnected, network environment (including infrastructure, systems, processes, people) in which data is shared timely and seamlessly among users, applications and platforms. By securely interconnecting people and systems, independent of time or location, net-centricity enables substantially improved military situational awareness and significantly shortened decision making cycles. Users are empowered to better protect assets; more effectively exploit information; more efficiently use resources; and unify our forces by supporting extended, collaborative communities to focus on the mission.

The concept of net-centricity has been gaining momentum since its introduction in the mid-1990s. Former Secretary of Defense (SecDef) Donald Rumsfeld believed in the concept and worked hard to make it a priority during his time in office (Joyner 2005). He appointed retired Vice Admiral Donald Cebrowski, one of the authors of *Network*

Centric Warfare: Developing and Leveraging Information Superiority, as the director of the then newly formed Office of Force Transformation (Defense Information Systems Agency 2009). The Office of Force Transformation sought to implement NCW throughout the DoD and, although the office was disbanded soon after the death of Admiral Cebrowski, the concepts are still present in many military operations today. It is evident in many of the examples seen later in this research, that network-centricity is an implied goal of many systems currently being built for the DoD. Next, we look to understand what information sharing and information discovery contribute to network-centric systems.

E. THE ROLE OF INFORMATION SHARING AND INFORMATION DISCOVERY IN NETWORK CENTRIC SYSTEMS

To aid in understanding what NCW—and the power of a well-networked force—can accomplish for the DoD and the military, four basic tenets of NCW are introduced. These four tenets are (United States Department of Defense Office of Force Transformation 2005):

- A robustly networked force improves information sharing
- Information sharing enhances the quality of information and shared situational awareness
- Shared situational awareness enables collaboration and self-synchronization, and enhances sustainability and speed of command
- These, in turn, dramatically increase mission effectiveness

These tenets describe how a warfighting force can develop and improve their power by drawing on the information provided by fully realized network. The NCW Hypothesis, shown in Figure 9, demonstrates a graphical view of the tenets of NCW as it traverses through the four domains of warfare: information, cognitive, social, and physical.

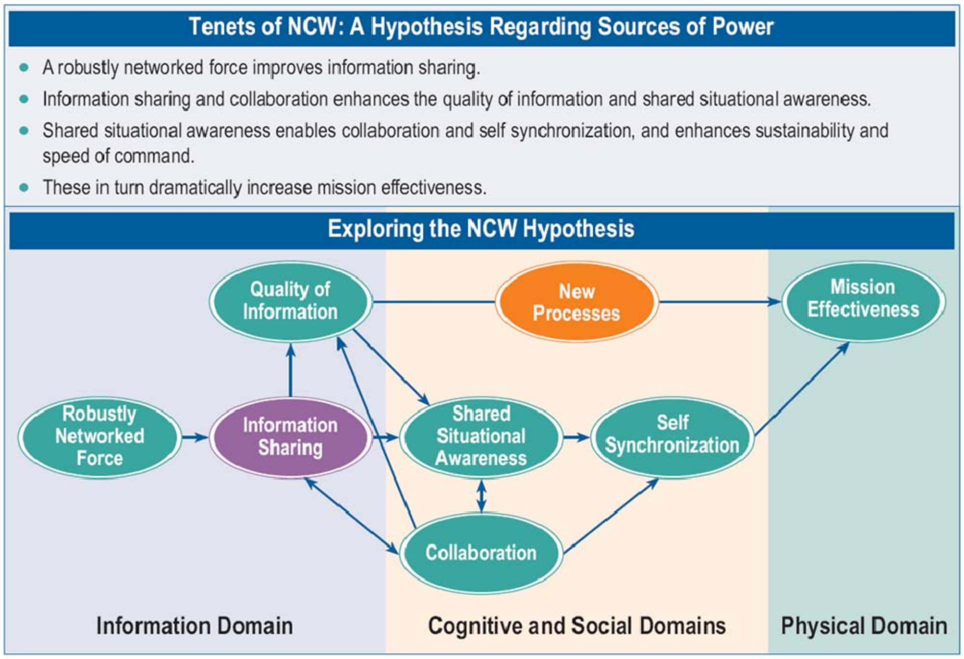

Figure 9. Tenets of NCW (From United States Department of Defense Office of Force Transformation 2005, 19)

The NCOW doctrine requires the four warfare domains are considered when deciding on the attributes and capabilities of a military force. The *information domain* is the domain in which information is created and shared amongst forces. This domain includes sensors and processes that enable military units to establish communication among warfighters. The *cognitive and social domains* occur in the mind of the warfighter. It includes the leadership qualities a military member may possess, as well as experience with battlespace concepts and tactics. Human interactions also occur in this domain, as shared awareness and shared understanding of the situation takes place through collaboration among military units. Finally, in the *physical domain*, are where the more traditional aspects of military warfighting occur. This domain includes the environments (land, sea, air, space) where forces are able to use military platforms to achieve mission effectiveness (United States Department of Defense Office of Force Transformation 2005).

Information sharing, which lies in the information domain, is central to NCW's hypothesis regarding sources of power. Once a comprehensive network is established, information sharing can occur and collaboration among different elements in a warfighting force with the same objective can take place. "The continuous sharing of information from a variety of sources enables the fully networked joint force to achieve the shared situational awareness necessary for decision superiority" (United States Department of Defense, Director for Operational Plans and Joint Force Development). Information sharing enhances shared situational awareness to other entities in the network. The eventual result of these processes, if successful, is an increase in mission effectiveness.

This chapter introduced the concepts of NCOW by discussing the history of full spectrum dominance and the strategic changes that have evolved in the military from the Industrial Age into the Information Age. The concept of information superiority and the GIG, and their contributions towards achieving net-centricity, was also explained. Finally, the role of information sharing and information discovery in network-centric systems was explored to highlight the importance of these concepts to the DoD. The next chapter explains the importance of information sharing and information discovery and defines these terms for the remainder of this thesis.

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III. OVERVIEW OF INFORMATION SHARING AND DISCOVERY SYSTEMS

When information sharing works, it is a powerful tool.
– National Commission on Terrorist Attacks upon the United States

This chapter explains the importance of information sharing and information discovery and defines these terms as the basis of this study. Several concepts that contribute to information sharing and information discovery are discussed to give the audience background information and a framework for these (often) unfamiliar terms. A survey of DoD information sharing and discovery systems is conducted to give the audience examples of current tools and services that are available to warfighters. Upcoming industry trends are discussed to highlight the potential of future information sharing and discovery capabilities.

A. INFORMATION SHARING

Information sharing recently came into the spotlight due to the media attention the term gained during the work of the 9-11 Commission from 2002 to 2004. The National Commission on Terrorist Attacks Upon the United States (also known as the 9-11 Commission), "an independent, bipartisan commission created by congressional legislation and the signature of President George W. Bush" (National Commission on Terrorist Attacks upon the United States 2004), was tasked with conducting an extensive and complete investigation into the events that led to the infamous terrorist attacks on September 11, 2001. In addition to the full report, the Commission was also mandated to provide recommendations designed to guard against future attacks (National Commission on Terrorist Attacks upon the United States 2004). In their final report the Commission identified several pre-existing factors that led to the attack and made strong and specific recommendations to counteract future terrorist efforts against the United States. One such recommendation was that the government should focus more effort into creating a better system for agencies to share information with each other. The 9-11 Commission cited the lack of information sharing amongst government agencies as a contributing

factor the attacks and they proposed that reform occur in the government to enable information to "be shared horizontally, across new networks that transcend individual agencies" (National Commission on Terrorist Attacks upon the United States 2004). It is important for the government to draw upon the important lessons from the 9-11, such as how information sharing is significant to any operation, whether it is the defense of the country or commercial industry endeavors.

Information sharing is an operational necessity that is not always planned for, but expected to occur. Often times, it is expected to happen seamlessly. Part of the reason may be that, not only is the term not well known, but it is also not well defined. Therefore, there is a problem when designing and implementing an ISD system. In spite of the importance of information sharing and information discovery, there is currently no specific guidance that identifies what ISD systems entail. There is an absence of basic elements of the systems engineering approach and design for ISD systems. As was seen in the previous chapter, an outline for the operational concept of ISD systems is discovered in the NCOW tenets. However, other elements necessary in the systems engineering approach are absent, such as: requirements; external systems context; interface guidance; and system architecture. Also, terms, definitions, and key concepts about the important elements of information sharing and information discovery are not standardized, so it is often hard for a user to comprehend what capabilities they need in an ISD system. Acquiring and/or developing ISD systems can, too, be difficult for DoD acquisition professionals because of the lack of collective DoD and industry terms and perceptions.

Information sharing invokes a wide variety of definitions, all of which may be partially true. There are currently several synonymous meanings of the term. To share—to allow somebody or something to use something—has several meanings depending on what context a person is sharing. Objects, information, data, and knowledge can all be shared. There is an infinite amount of ways in which something, like information, can be shared. Information sharing protocols, such as extensible markup language (XML), simple object access protocol (SOAP), and Web services description language (WSDL),

are tools that allow structured information to be shared via the Internet. Or more simply, a discussion between people within an organization can enable information sharing, as well.

The Department of the Navy Chief Information Officer's (DON CIO) information sharing definition is used (Department of Navy Chief Information Officer 2008):

> Information sharing is making information available to participants (people, processes or systems). It includes the cultural, managerial and technical behaviors by which one participant leverages information held or created by another.

Due to the completeness and applicability of this definition to the topics covered, this study continues to use the DON CIO's definition of information sharing for the remainder of this research. The next section focuses on the difference between data, information, and knowledge, and explains how information enables action to occur.

B. KNOWLEDGE HIERARCHY

Information is fundamental to understanding <u>any</u> situation. This revelation allows us to appreciate why information *sharing* is absolutely crucial to successful military operations. When information is not shared there is no basis, or context, that a person may be able to relate to. Situational awareness is when information and knowledge about the perception of the environment is translated into a requisite level of common understanding across the spectrum of participants. Without the proper structure to share information, situational awareness is "lost". Lack of information further complicates the circumstances of a situation, causing participants in a scenario miss key "pieces of the puzzle," and hinders direct action to be taken.

However, not all "information" is valuable and worth sharing and discovering. It is important to discuss what many academics refer to as the Knowledge Hierarchy (Nissen 2006, 16–17) when discerning if information will help a situation. Information can be shared and discovered at different levels and in varying degrees of abundance. This hierarchy attempts to model the hierarchy of data, information, and knowledge, and shows how each builds on the other. Figure 10 illustrates the Knowledge Hierarchy concept.

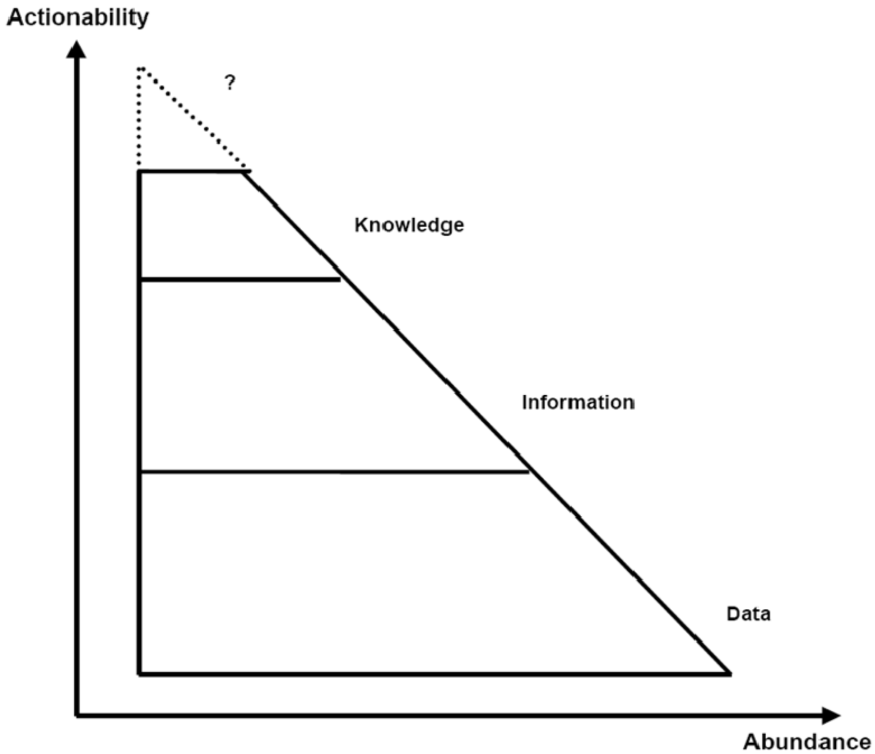

Figure 10. Knowledge Hierarchy (From Nissen 2006, 17)

The Knowledge Hierarchy shows the complementary nature of data, information, and knowledge. Each component has unique characteristics, and relies on other elements to be useful (Nissen 2006, 17).

The x-axis represents the abundance of the data, information, and knowledge. *Data*—facts, figures, text, and images—is the most abundant of the three levels, as it is relatively easy to acquire with today's technological resources. Data is needed to produce information, which lies higher on the hierarchy. *Information* is produced when data is used in some context, or when there is meaning assigned to the data. Information enables a person to understand their environment and gives context to decisions that need to be made. Information along with other factors (education, experience, training) is necessary to produce *knowledge*. Knowledge is the most coveted of the three constructs because it supports action directly. The "?" at the level above the knowledge indicates

what some academics believe is another level of knowledge, such as: wisdom, intelligence, or enlightenment (Nissen 2006, 19). This study does not address this level as it is beyond the scope of our purposes.

The y-axis of Knowledge Hierarchy represents the actionability of data, information, and knowledge. Of the three, data is the least actionable because it lacks background and meaning in a situation and is rarely enough to base a substantive action. Information is more likely to produce definitive action because contextual circumstances are available. Likewise, knowledge produces the most actionability because factors such as education, experience, and training, add value to the decision for action (Nissen 2006, 21). All steps in the Knowledge Hierarchy (knowledge, information, and data) may enable a person to take some level of action. However, knowledge can enable a person to take direct action to progress a situation (Nissen 2006, 19). Of course, knowledge is usually more useful to have in a precarious scenario, such as during wartime. However, as Figure 10 illustrates, knowledge is harder to gain and much less abundant than data and information. This is because knowledge often requires many other factors that take time to acquire (i.e., experience or on-the-job training), so it is not practical to expect that knowledge will flow as fast as data and information can.

Sharing and discovery occurs at each level of the Knowledge Hierarchy. This study is concerned with sharing *information* because it is the most realistic level we can hope to achieve with the unique constraints (time, environment, network, etc.) that are found in the DoD. Thus, it is important to understand how to ensure that information flows well throughout the DoD and military organizations. The next section will explain the concept of information discovery and discuss some examples of how information discovery is applied in the DoD.

C. INFORMATION DISCOVERY

The key benefit of information sharing is that it can lead directly to information discovery. *Information discovery*, much like information sharing, is a term that is often unclear. It is defined as: "browsing through collections returned by search engines, and forming collections of relevant results" (Kerne and Smith 2004). *Information discovery*,

in the context of this study, is characterized by iteratively reformulating problems, manipulating representations, and finding solutions and it often involves integrating multiple information resources (Kerne and Smith 2004).

The type of information discovered depends substantially on the Community of Interest (COI) pulling or pushing (or providing/accepting or publishing/subscribing) the requested information. A COI is (Assistant Secretary of Defense for Networks and Information Integration/Department of Defense Chief Information Officer 2004):

> A collaborative group of users that exchanges information in pursuit of its shared goals, interests, missions, or business processes and therefore must have shared vocabulary for the information it exchanges.

The role of the COI is to identify information gaps and direct information discovery. The COI (informally) defines the need for the information discovery that must occur. The intrinsic structure of the DoD reveals several COIs already "built-in" to the military organization. For example, the Navy has several warfare areas that comprise the overall mission of the service, such as: undersea warfare (USW); surface warfare (SW); anti-submarine warfare (ASW); and air warfare (AW). Each of these warfare areas can be considered a COI because the group of users within each warfare discipline is concerned with objectives specific to *their* mission. A user in the USW COI, for example, may not be necessarily interested in information that is discovered for a user in the ASW COI.

COIs may be formulated at any level, and at varying capacities. If more granularity is necessary in a mission, lower-level COIs can be formed. Or, if a COI is needed that is comprised of several users from varying other COIs, a completely different (and specific) COI can be formed to meet that goal also. A COI exists if a collaborative group of users are exchanging information to pursue the same objectives.

Discovered information is actionable, and defined by the needs of a COI. Next, we discuss how information sharing and information discovery are enabled by the use of information technology.

D. INFORMATION SHARING AND INFORMATION DISCOVERY IN THE NETWORK-CENTRIC WORLD

Information sharing and information discovery can occur via different processes. Traditionally, information sharing was seen as an event that occurred between a sender and a receiver in a one-to-one relationship. The advent of information technology introduced several other sharing patterns: one-to-many, many-to-one, and many-to-many. The principles of information sharing and discovery, and the military objective of realizing a fully-functioning GIG, are centered on the concept of a successful 'many-to-many' sharing pattern.

Information sharing and information discovery also occurs at different levels, depending on the scope of information that is necessary. In the case of the 9-11 Commission, it was discovered that information sharing needed to occur at high levels between government agencies that had organizational knowledge of information leading to the attack. However agencies were not able (at the time), or were not aware that they should, share certain information with other agencies. Some information sharing occurs, on a smaller scale, as in between directorates, divisions, or personnel communicating information to advance their business. Whatever the scenario and the number of participants, at the backbone of information sharing and information discovery is the network that enables it to occur. Information technology, information systems, information communications, the internet, and Web-enabled services allow information to be communicated at an expedited rate and are the vehicles for information sharing and information discovery to transpire.

In the article, "Findings of Network-Centric Systems Engineering Education," Goshorn discusses the problems and needs for Network-Centric Systems Engineering (NCSE) education. The author defines four core approaches in the "network-centric world" that overlap each other, yet, have independent functions. The four overlapping approaches are:

- Top-Down Approach
- Bottom-Up Approach
- Middle Approach of smart push/smart pull
- Side View Approach

These four overlapping approaches can be seen in Figure 11. The top-down approach includes the fundamentals of information sharing through the internet and enterprise services. The bottom-up approach covers the fundamentals of distributed systems and includes systems such as smart sensor networks. The middle approach connects the top-down and bottom-up and is the necessary link to push and pull information between these approaches. The side view approach extends communications to the tactical edge and is crucial for disadvantaged users to get their information (Goshorn 2008).

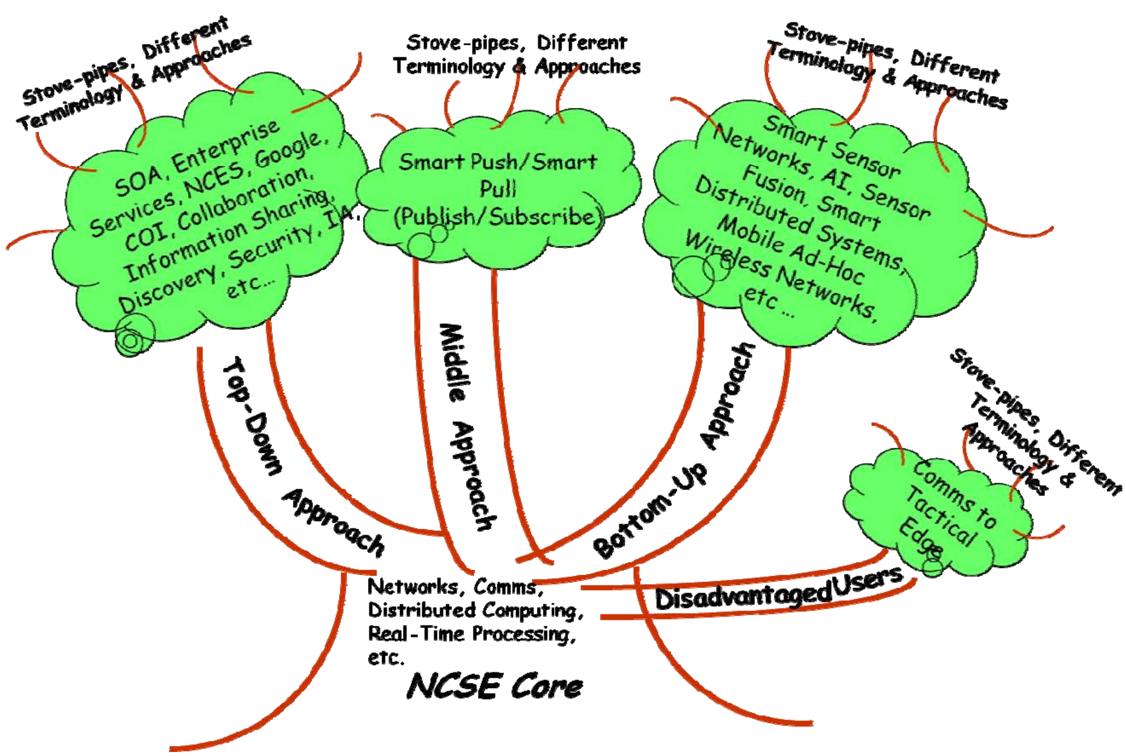

Figure 11. The problems and needs discovered in the network-centric world (four overlapping approaches) (From Goshorn 2008)

Figure 11 shows that information sharing and information discovery reside in the top-down approach. In addition to the overlapping approaches, and to integrate the NCSE core, Goshorn points out that the basis for all of the approaches (located at the trunk of the NCSE Core "tree") are an understanding of the fundamentals of networking and communications. This NCSE Core allows the four approaches to function properly together. From a systems engineering perspective, a network-centric system must include all four approaches. Each approach can be viewed as a sub-system, or as a system, in a system of systems. This perspective is discussed and developed in chapter IV.

E. INFORMATION SHARING AND DISCOVERY (ISD) SYSTEMS

Information sharing and information discovery can occur at different levels and at varying capacities. The scope of this study focuses primarily on the type of information sharing and discovery that occurs via Web-enabled services and that encompass many of the elements seen in Figure 11's top-down approach. Another aspect of the information sharing and information discovery is seen in Figure 12.

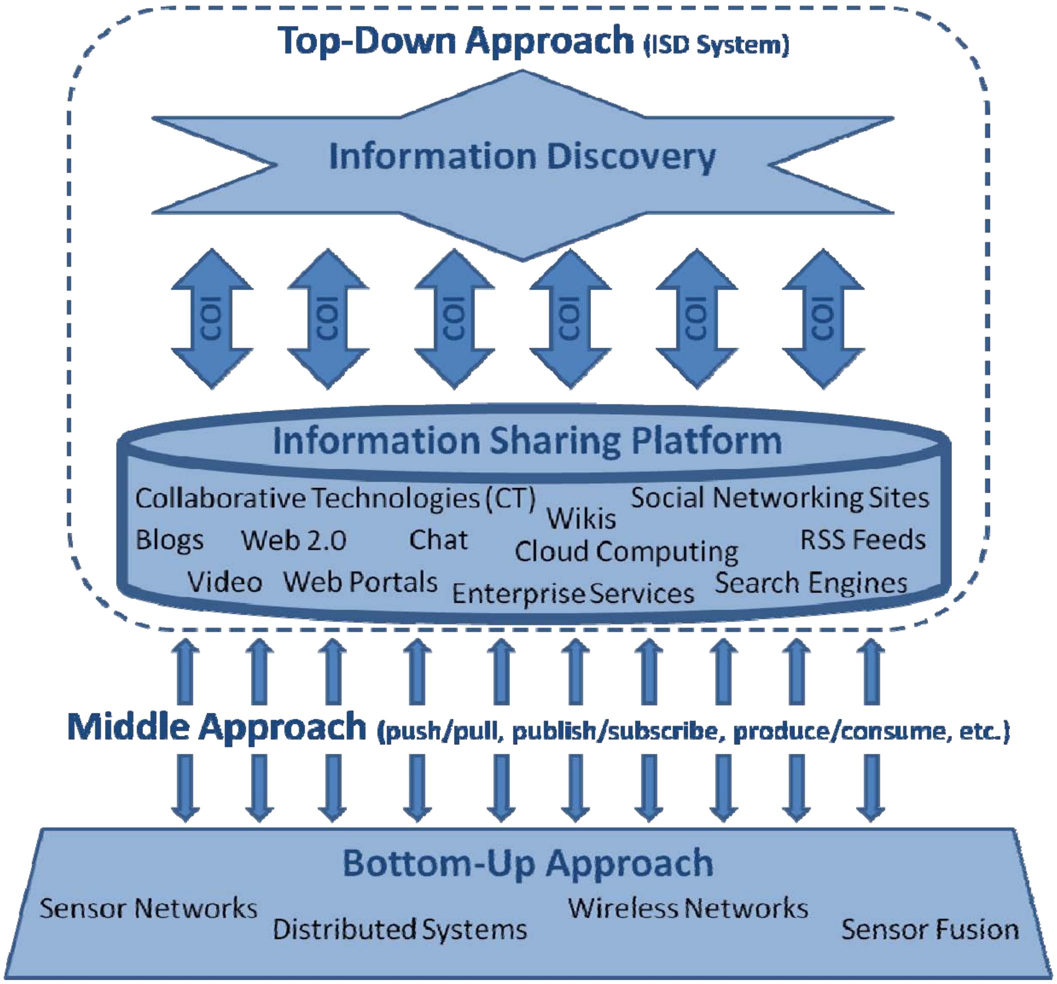

Figure 12. Information Sharing leads to Information Discovery

Taking into account the four approaches introduced in the NCSE core, Figure 12 illustrates that information sharing and information discovery are found in the top-down approach. The bottom-up approach contains the many devices and sensors that collect raw data. The middle approach embraces the actions taken via human, or through artificial intelligence, to move the data to venues that will allow processing, sorting, and filtering. The top-down approach is where the information sharing platform is located. It is made of an abundance of Web-enabled tools and services such as: wikis; blogs; Web portals; search engines; enterprise services; and collaborative tools. These tools form the foundation, or the information structure, for information sharing to occur. Subsequently, using systems within the information sharing domain enable COIs to discover information that is relevant to their mission.

Figure 12 will be referenced as a generalized ISD system model throughout the remainder of this thesis. Several of the concepts and examples surveyed in this study will map directly to the functions explained in Figure 12.

With the basis of the top-down approach firmly established, the next section focuses on examples of DoD ISD systems being used at this time.

F. EXAMPLES OF INFORMATION SHARING AND DISCOVERY TOOLS CURRENTLY IN USE BY THE DOD

The concept of NCOW and the objective for the military to achieve net-centricity is outlined in *Joint Vision 2010* (United States Joint Chiefs of Staff 1995) and the subsequent *Joint Vision 2020* (United States Joint Chiefs of Staff 2000). These DoD-sponsored information guides discuss the military's goals to become more network-centric and to achieve full spectrum dominance. In the endeavor to attain these objectives, the DoD has employed several systems that are capable of sharing and discovering information.

The following sub-sections survey a sample of some of these DoD systems. Each example is described and examined to establish the relationship they have to the top-down approach (ISD system), seen in Figure 12 (Information Sharing leads to Information Discovery).

1. FORCEnet

The Navy, Marine Corps, and Coast Guard Team employ the network-centric system functional concept of FORCEnet for their 21st century strategy. FORCEnet is the concept for naval command and control for joint operations and supporting activities in 2015-2020. It is an innovation that is predicted to have dramatic and wide-ranging implications for the naval services because its intent is to establish a common direction for future naval command and control capabilities (Clark and Hagee 2005). An underlying premise of this operational construct and architectural framework is that FORCEnet will gets its power is the "network effect," which causes the value of a product or service in a network to increase exponentially as the number of those using it

increases (Clark and Hagee 2005). This is the same notion that was previously described in Chapter II's section regarding Metcalf's Law.

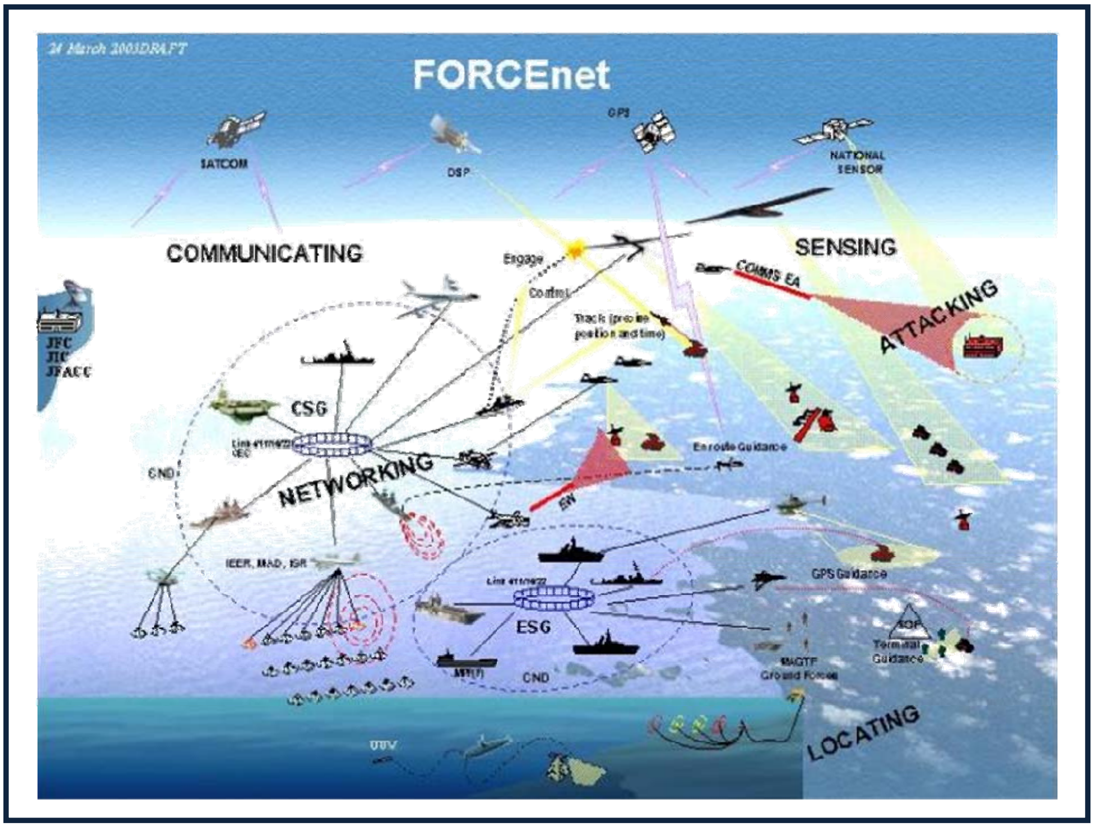

Figure 13. FORCEnet Operational Concept (From Sharp 2003)

In essence, FORCEnet is the Navy, Marine Corps, and Coast Guard's answer to the naval implementation of the GIG. The Air Force and Army offer their own versions of the GIG with C2 Constellation Net (Air Force) and LandWarNet (Army). Figure 13 shows a broad view of what FORCEnet seeks to attain through the network of sensors, platforms, personnel, and information technologies. Since it is a representation of the GIG (on a smaller scale—for the Navy, Marine Corps, and Coast Guard), FORCEnet encompasses many elements from all of the network-centric approaches. For example, sensor networks and wireless communications are included from the bottom-up approach. The middle approach is seen in the exchange of information among sensors and platforms. The top-down approach can be seen in all aspects of Figure 13, as well. The "communicating" realm of FORCEnet, which involves the movement of information, is

what is referred to in Figure 12's information sharing platform. In addition, there are many COIs (logistics, warfare, intelligence gathering, etc.) within FORCEnet that direct the type of information discovery that is pertinent to the mission objectives that are being pursued.

Central to the success to FORCEnet are the set of capabilities deemed as necessary to implement the concept. These are (Clark and Hagee 2005):

- Provide robust, reliable communication to all nodes, based on the varying information requirements and capabilities of those nodes.
- Provide reliable, accurate and timely location, identity and status information on all friendly forces, units, activities and entities/individuals.
- Provide reliable, accurate and timely location, identification, tracking and engagement information on environmental, neutral and hostile elements, activities, events, sites, platforms, and individuals.
- Store, catalogue and retrieve all information produced by any node on the network in a comprehensive, standard repository so that the information is readily accessible to all nodes and compatible with the forms required by any nodes, within security restrictions.
- Process, sort, analyze, evaluate, and synthesize large amounts of disparate information while still providing direct access to raw data as required.
- Provide each decision maker the ability to depict situational information in a tailorable, user-defined, shareable, primarily visual representation.
- Provide distributed groups of decision makers the ability to cooperate in the performance of common command and control activities by means of a collaborative work environment.

- Automate certain lower-order command and control sub-processes and to use intelligent agents and automated decision aids to assist people in performing higher-order subprocesses, such as gaining situational awareness and devising concepts of operations.
- Provide information assurance.
- Function in multiple security domains and multiple security levels within a domain and manage access dynamically.
- Interoperate with command and control systems of very different type and level of sophistication.
- Allow individual nodes to function while temporarily disconnected from the network.
- Automatically and adaptively monitor and manage the functioning of the command and control system to ensure effective and efficient operation and to diagnose problems and make repairs as needed.
- Incorporate new capabilities into the system quickly without causing undue disruption to the performance of the system.
- Provide decision makers the ability to make and implement good decisions quickly under conditions of uncertainty, friction, time, pressure, and other stresses.

These capabilities require developmental efforts across six dimensions: physical, information technology, data, cognitive, organizational, and operating. Many of FORCEnet's capabilities are seen as functions of the ISD system, discussed in Chapter V of this thesis.

2. Net-Centric Enterprise Services (NCES)

The DoD's Defense Information Systems Agency (DISA) NCES has made great strides in enabling information sharing and discovery as a primary objective to connect systems that have information (data and services) with people who need information. This is a major principle of the top-down approach (Figure 12) and of ISD systems. The

mission and vision of this NCES is to “enable the secure, agile, robust, dependable, interoperable data-sharing environment for DoD where warfighter, business, and intelligence users share knowledge on a global network” (Defense Information Systems Agency 2009).

NCES consists of four primary product lines (Figure 14): Collaboration; Content Discovery and Delivery; Portal; and Service Oriented Architecture Foundation (SOAF) (Defense Information Systems Agency 2009).

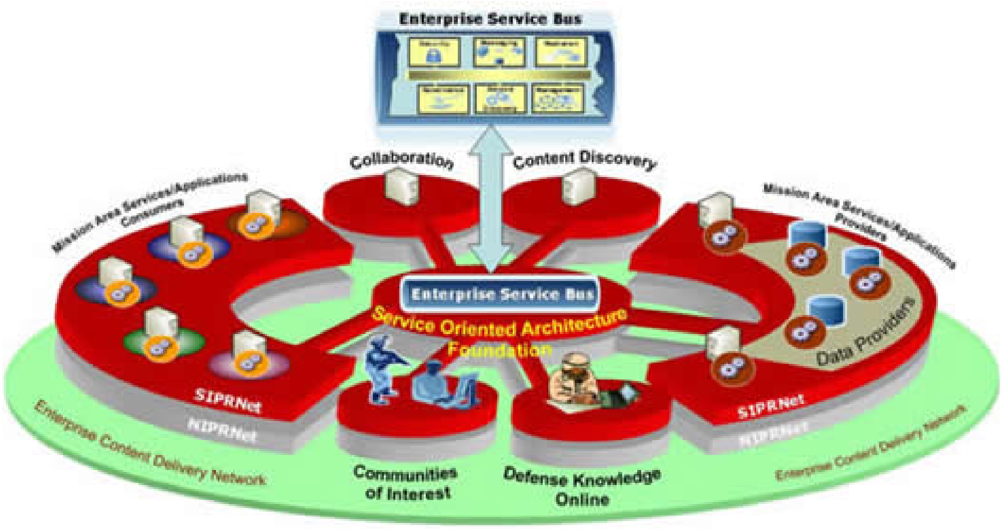

Figure 14. NCES Product Lines (From Defense Information Systems Agency 2009)

In recent years, DISA’s products and capabilities have been steadily making their way into the hands of the military components. There have been increases in the use of the NCES product line as their resources are making life (and work) easier for end-users. The following sub-sections are a sampling of the more popular NCES procurements that have seen a recent rise in use:

a. Defense Knowledge Online (DKO)

As the DoD's enterprise portal, DKO provides users access to NCES, as well as a full suite of portal services. DKO was adopted and derived from the Army Knowledge Online (AKO) which is the Army's gateway to services, applications, and

content (NCES Website), because AKO is the largest of all the DoD portals (Jones 2007). The Navy and the Air Force have their own service portals as well: Navy Knowledge Online and the Air Force Portal.

DKO offers the following services (Defense Information Systems Agency 2009):

- User Access to NCES services including the DoD Collaboration Services
- Organizational Web Sites and Folders (virtual spaces)
- Team Sites and Personal Sites for File Sharing
- Webmail (email address for life) with calendar
- Groups - user or organizationally defined teams to support collaborative activities
- Forums - threaded discussions
- Single Sign On to hundreds of services and applications via DKO

Figure 15. AKO/DKO Web Portal (From Defense Information Systems Agency 2009)

The DKO Web portal is an excellent example of the top-down approach and of an ISD system because it enables information sharing and information discovery through a variety of tools. DKO utilizes information sharing collaborative tools such as forums and email (a user may apply for their own email account through the site). It provides access to information repositories—compiled/stored information for users from various sources—for use in various mission areas. Likewise, it acts as a social networking site for members to engage in forums, online-discussions, and training.

This broad ISD system is meant for the all the users in the DoD (Army, Navy, Air Force, etc.). Thus, the portal has subsections that allow COIs to communicate with each other and discover necessary information regarding mission planning and command and control processes.

b. Defense Connect Online (DCO)

DCO is a commercially managed service that DISA acquired, from Carahsoft and partners Adobe and Jabber, to meet DoD collaboration requirements. It is an enterprise solution for collaborative internet protocol (IP)-based audio and video over IP conferencing (Department of Defense 2009). This Web conferencing tool allows other key features (Figure 16) such as shared desktop and embedded text chat functions, as well.

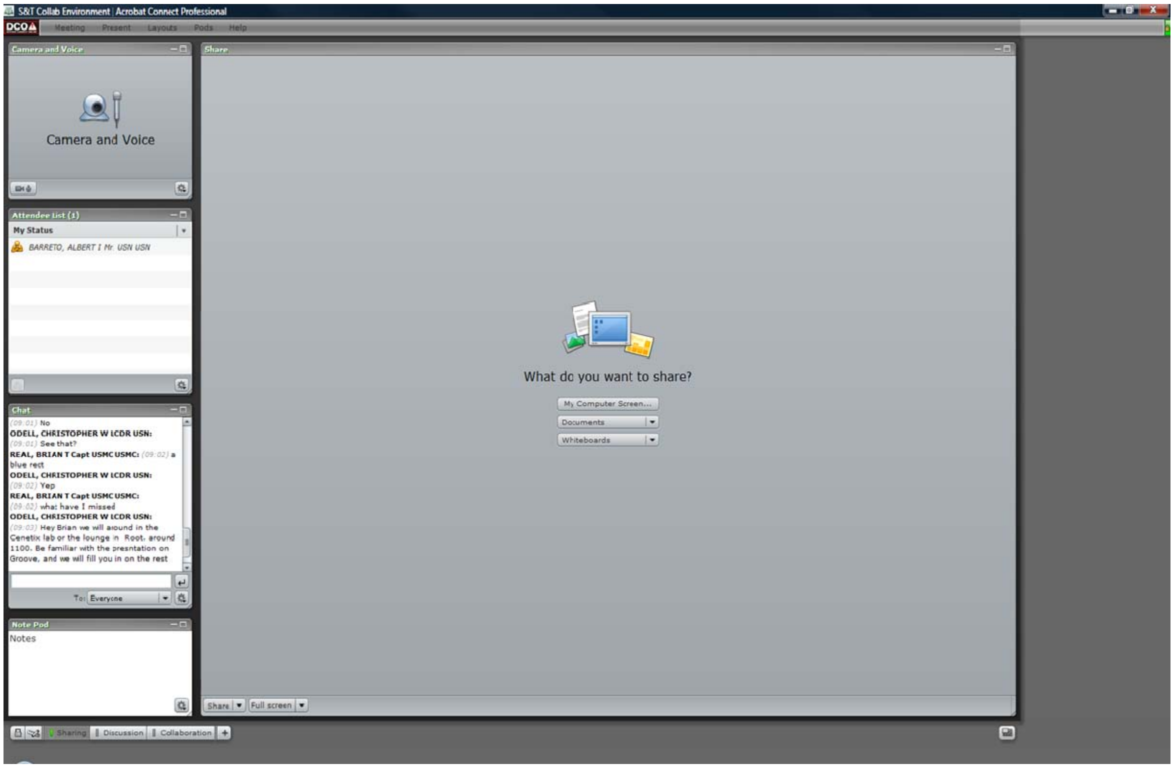

Figure 16. DCO Desktop Sharing Mode (From Defense Information Systems Agency 2009)

DCO is an example of a suite of collaborative tools with limited data storage. Like DKO, it has seen a surge in users recently because of the easy functionality of its services. Figure 16 provides a snapshot of a DCO common (home screen) configuration with chat, note pad, video/audio options, and member file sharing. DCO is an excellent collaborative tool that is gaining in popularity with users; however, it represents only a small portion of an ISD system's functions. The system's functions enable information sharing, but as Chapter V discusses, the ISD system also collects, processes, and distributes information relevant to the mission (information discovery). These are key functions that DCO does not deliver yet. Therefore, it is categorized as a collaborative tool only.

c. Content Discovery and Delivery

Of all of DISA's NCES products, the Content Discovery & Delivery line is most aligned with the functions of the ISD system because it provides information advertisement, discovery, and efficiency. Content Discovery is concerned with enhancing the visibility of information products between the producers and the consumers of the GIG. This portion of the product line allows information producers to make their information available for discovery by COIs. The goals of this program are to increase information sharing and to increase overall awareness in the type of information available through DISA search tools: Centralized Search, Federated Search, and Enterprise Search (Defense Information Systems Agency 2009).

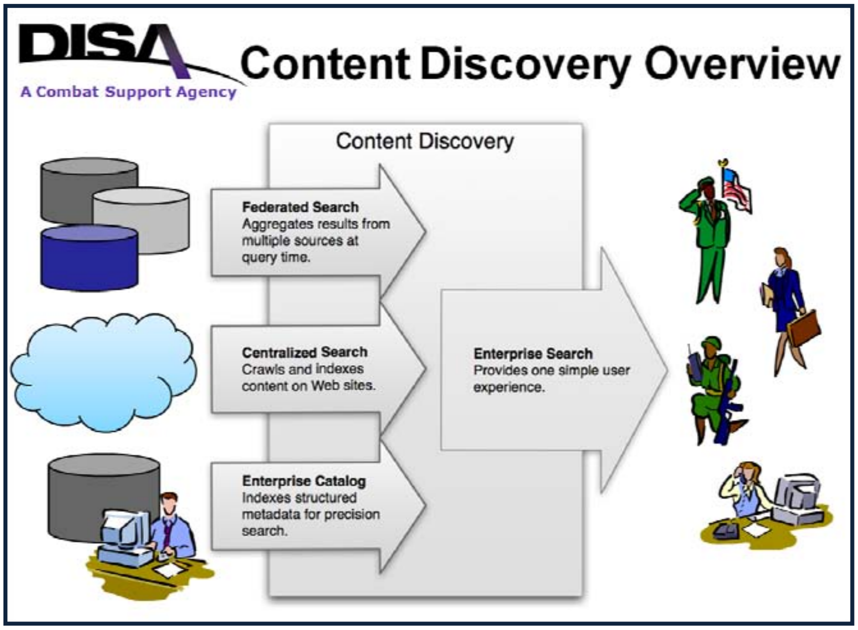

Figure 17. Content Discovery Overview (From Defense Information Systems Agency 2009)

Content Delivery supports the delivery of information to users. Currently, this DISA NCES product line offers two content delivery capabilities: Enterprise File Delivery (EFD) and GIG Content Delivery Service (GCDS). EFD allows peer-to-peer file replication capability as a way to synchronize large file storage between geographically dispersed sites. GCDS is a commercially owned, globally distributed computing platform comprised of servers deployed across the Defense Information Systems Network (Defense Information Systems Agency 2009). This product is meant to provide information assurance and secure delivery of data to geographically separate COIs.

The NCES' Content Discovery & Delivery has many of the features of the ISD system, segmented into its different product lines. It is the basis of a good start for the GIG because the information sharing and discovery capabilities support the DoD data strategy to make information more readily available. Of all of NCES' product lines, Content Discovery & Delivery caters the most to COIs. The search functions available in this product suite attempt to aid COIs that require extensive searching for mission information through the use of the Centralized Search, Federated Search, and Enterprise

Search services. Likewise, EFD and GCDS support COIs in discovering information by making information assurance and delivery easier between them.

There are currently several ISD tools available for use in the DoD. Each offers specific contributions to the network-centric top-down approach, and most products are still being operationally tested by the military services. Next, we look outside of the DoD, to examine existing industry developments that may provide value to future ISD system development and procurement.

G. RELEVANT INFORMATION SHARING AND DISCOVERY INDUSTRY TRENDS AND DOD IMPLEMENTATION

The DoD has capitalized on several information sharing and information discovery developments in recent years. However, there is a constant stream of new technologies in this field and, still, many more commercial advances that can be incorporated for use by the military. The commercial industry introduces innovative new concepts that may potentially change the composition of the military strategy and warfighting in the future. Some of the latest trends found in industry, of which many are already finding their way into DoD discussions, are summarized in the following sections.

1. Service Oriented Architecture

Service Oriented Architecture (SOA) has been a buzzword in the commercial information technology industry for a several years now because its principles are revolutionary. It is architecture for distributed systems based on common standards and practices and the loose coupling of services. The result of this architecture is the flexibility and agility of services that were not previously perceived as being interchangeable or reusable. SOA enables an environment that promotes information sharing by advocating using information technology systems that allow the using existing assets, rather than duplicating efforts within an organization. This concept promotes a way to easily facilitate changes that business may need to accommodate industry progression. The concept encompasses technological changes, as well as business changes (Hurwitz, et al. 2006).

Leveraging SOA in the DoD is a valid notion because the architecture attempts to close gaps in information sharing and information discovery by using common standards to exchange information and creating an information structure that is accessible to qualified users in the network. This differs from many of the existing legacy stove-piped systems that require specific and unique networks to operate and maintain.

The concept of SOA and ISD systems complement each other well as the functions of the ISD system, discussed in more detail in Chapter V, mirror the basic principles of SOA. ISD systems provide relevant information from reputable sources and distribute data to users so that they may carry out their mission. Like the network-centric top-down approach, the objective of SOA is to be able to share common tools or services in order to facilitate mission effectiveness. For ISD systems, the common services are found in the information sharing platform (Figure 12). For SOA, the common tools are standards and services that may be utilized (and re-used) by several assets/systems. The industry standards introduced from SOA will aid in the current and future DoD design and acquisition of ISD systems.

The following sub-sections further discuss the concept of SOA's Enterprise Services (Bus), and will examine two examples of the SOA implementation in DoD applications.

a. Enterprise Services

Enterprise services, sometimes referred to as the Enterprise Service Bus, provide the software infrastructure that enables the use of SOA because it allows the integration and use of common components within an organization (Progress Software 2009). The information sharing platform (Figure 12) provides a similar aspect in the network-centric top down approach by acting as a repository of common services/tools that facilitate COIs in information discovery. The concept of net-centricity, discussed in detail in Chapter II, is analogous to enterprise services because each allows systems to provide necessary information to the right people ubiquitously. The enterprise service bus consists of the software components that direct information from one user to another.

Since the DoD community continually needs to share and retrieve information, enterprise services can provide the essential platform to combine internet technologies and the vast network power of the DoD.

b. DISA NCES Service Oriented Architecture Foundation (SOAF)

SOAF, another of DISA's NCES product lines, aims to provide the network infrastructure for SOA to thrive in the DoD. The goals of the SOAF are to (Lewis 2006):

- Provide the infrastructure to enable the evolution and operation of interoperable and secure service-oriented computing within the DoD and with partners and allies (Homeland Security, coalition partners, commercial industry)
- Enable consumers to discover available services, determine which services meet their mission requirements, and securely and reliably consume them
- Facilitate service providers' ability to publish services, report appropriate performance information and dependably support their customers
- Enable visibility into the performance of DoD enterprise services and their use in DoD mission and business operations
- Enable asset management and visibility of enterprise services that exist on DoD networks or are being developed for DoD networks

There are several SOAF Services (Figure 18): Enterprise Service Management, Machine-to-Machine Messaging, Service Discovery, Mediation, Service Security, and Metadata Services. In relation to the network-centric top-down approach (Figure 12), these services contribute to COI's capability to discover mission information by providing services that facilitate easier data search and publication. SOAF services

also monitor, manage, and support the transformation and exchange of computing services and data between users and their applications (Lewis 2006).

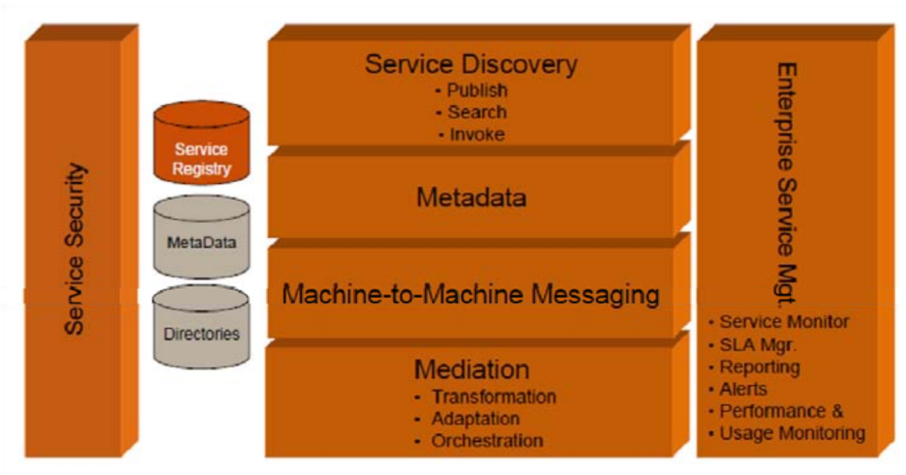

Figure 18. SOAF Services (From Lewis 2006)

c. CANES

To combat the problem of supporting so many legacy systems, and in anticipation of rising maintenance costs of these systems, the Navy embarked on a new initiative that would implement SOA, as well (Turner 2007). The Consolidated Afloat Networks and Enterprise Services (CANES) program uses the principles of SOA to allow for open-architecture in fleet-wide, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) capabilities networks by creating a common backbone with a common computing environment. The CANES common backbone is illustrated in Figure 19. The objective of the CANES system is to replace various stove-piped afloat networks with a single, common network system. This is in direct contrast to the present jumble of systems which exist on present-day ships. If the objectives of the CANES system are met, it would significantly impact the Navy because there will no longer be a need to manage several complex systems (and the integration issues that accompany them).

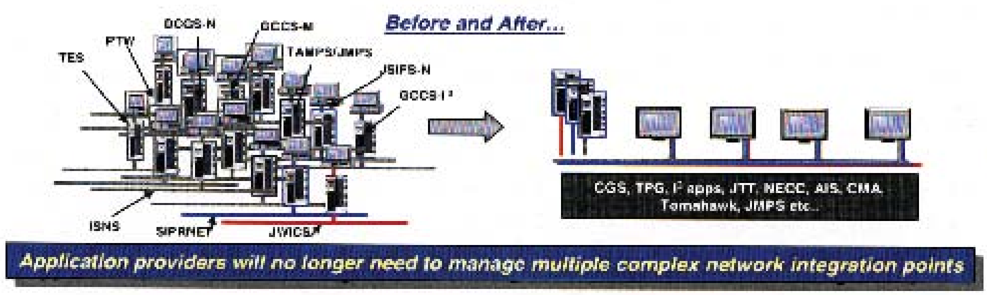

Figure 19. CANES Common Backbone (From Turner 2007)

The basic concept of CANES is to decouple the software from the hardware by permitting software updates without needing to outfit a platform new hardware to accomplish this. The primary goals of the CANES Program are to (Gourley 2009):

- Consolidate and reduce the number of afloat networks through the use of mature cross domain technologies and common computing environment infrastructure
- Reduce the infrastructure footprint and associated costs for hardware afloat
- Provide increased reliability, application hosting, and other capabilities to meet current and projected warfighter requirements
- Federate Net-Centric Enterprise Services (NCES) Service Oriented Architecture Core Services to the tactical edge to support overall DoD C4ISR application migration to a SOA environment

Since CANES is the Navy's implementation of SOA, the program is related to the network-centric top-down approach and ISD systems in an equivalent manner. The objective of CANES is to be able to share common naval systems' services in order to facilitate overall mission effectiveness. In ISD systems, the common services are found in the information sharing platform (Figure 12). In CANES, the common services are standards that may be utilized (and re-used) by several assets/systems.

2. Web 2.0

Contrary to what the term may suggest, the phrase “Web 2.0” does not refer to a technical update to the existing version of the World Wide Web (WWW). Rather, Web 2.0 is a term that conveys the collective changes in the usage of the WWW in recent years. Web development and Web design have been migrating to use of the internet network as a platform and focusing on services delivered over the Web platform (O'Reilly 2005).

Figure 20. Web 2.0 (After Anonymous 2009)

Like many newly introduced concepts, there is no concrete definition for Web 2.0. Figure 20 illustrates some examples of Web 2.0’s primary conceptual changes. There is more social affiliation with the Web, especially through the use of social networking sites (Facebook, MySpace, You Tube, etc.). Internet users are also more participatory now, contributing information via blogs, online forums, and chat rooms. The Internet is seen more as a tool or application, then an entity. The term fundamentally refers to the change from static *Hyper Text Markup Language* (HTML) Web pages to a more dynamic WWW. This “newer internet” is organized and based on providing Web applications to users. Web 2.0 functionality also includes more open communication with an emphasis on Web-based COIs, and more open sharing of information (Anonymous 2009)Web 2.0’s features incorporate many of the fundamental principles of information sharing and information discovery systems (Figure 12). The new adaptation

of the WWW contributes to the information sharing platform by enabling users to collaborate and share information online. Likewise, Web 2.0 facilitates the organization of COIs (discussion groups, forum topics), so that information is more easily discovered when needed. The push toward open communication and two-way sharing support the ideals of NCOW and of ISD systems.

3. Cloud Computing

"Cloud computing" is a relatively new concept gaining recognition in many IT and computing communities. The term refers to a computing model instead of a specific technology. In the Cloud Computing model—the "cloud" is a metaphor for the internet—all servers, networks, applications and other components necessary to data centers are made available to users via the WWW (Fogarty 2009).

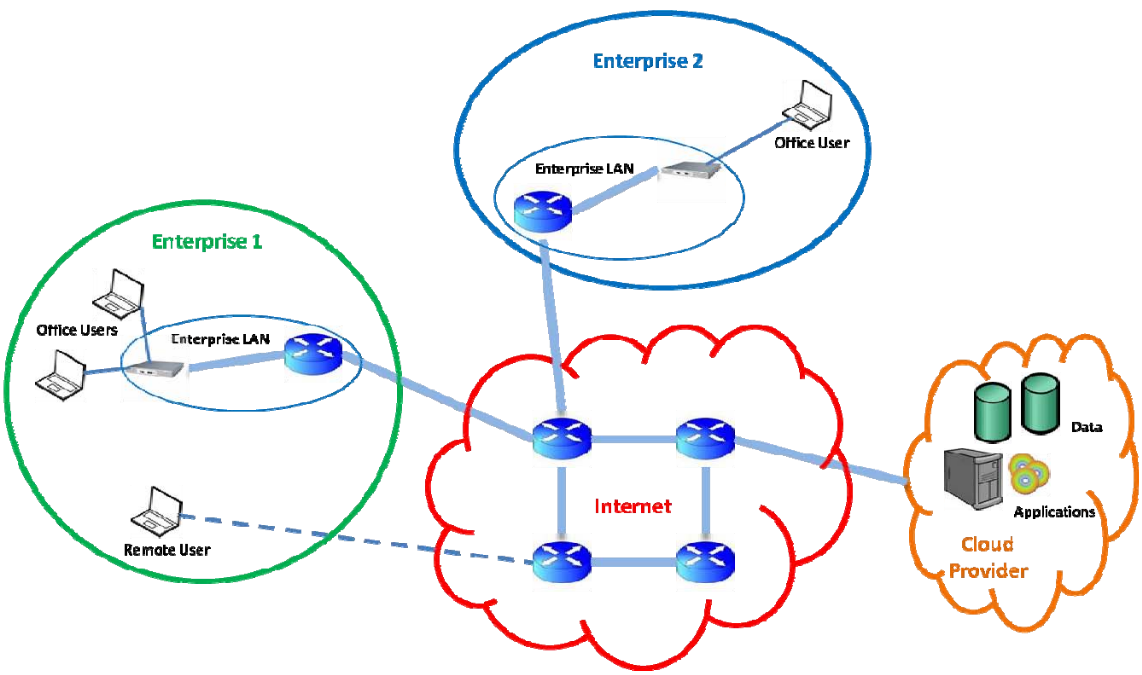

Figure 21. Cloud Computing Model (After Hanna 2009)

This computing model, shown in Figure 21, is significant because it does not require enterprise users to contract out these IT services to another entity. Instead, a business' IT staff need only purchase the type and amount of computing services they

need from a company selling the three basic types of Cloud Computing: Software as a Service (SaaS), Platform as a Service (PaaS), or Infrastructure as a Service (IaaS) (Fogarty 2009). Users are only required to "plug into" the cloud to access essential computing functions and to access their internal data center since this is where their information is stored, on servers belonging to the cloud-providing service.

Cloud computing contributes to the information sharing platform (Figure 12) by providing services that enable COIs to store/retrieve information so that it may be shared and discovered by other COIs. There are also many of similarities between cloud computing and SOA as both concepts promote the re-use of tools and services to enhance the availability of information ubiquitously to all users.

The cloud computing concept is so recent that the DoD has only just begun to debate its usefulness to the type of work that is done in the government. Of course, security is a primary concern because the basis of cloud computing requires that vital information be stored at a third-party facility in the conventional concept. There have been some discussions about creating a private cloud for the DoD to ensure that crucial data is protected from undesirable entities, but no tangible resolution has been reached.

4. Open Source Software Development

Another growing movement in computing and software development communities is the notion of delivering and deploying technology faster with the use of the open source software development. Open source refers to the availability of the computer source code for software. Users of open source software are allowed to use it as is, change it, or improve it for their own applications. The software can be redistributed freely, modified or not. The applications created by the software are potentially more useful and error-free over the long term. However, many professional developers also argue that the security of the code cannot be guaranteed free of harmful elements (backdoors, malicious code, etc.).

Open source software development's basic idea incorporates collaboration as the means for distributing source code. This contributes directly to the information sharing platform (Figure 12). Open source software development can enable information

discovery depending on the COI's needs. Furthermore, future ISD systems may even be developed using some open source software, so it is important to comprehend key features of this growing trend in software.

a. Forge.mil

In February 2009, DISA released a program that would support the use of open source software in the DoD. The Forge.mil collaborative environment, shown in Figure 22, is the DoD's approach to enable "rapid innovation to accelerate delivery of dependable software, services and systems to support net-centric operations and warfare" (Defense Information Systems Agency 2009). As illustrated in Figure 22, the program seeks to take tools, standards, and process from various sources (government, academia, industry) and re-use existing software and services to facilitate faster systems development efforts. SoftwareForge is the first component of Forge.mil's family of services to be deployed. It provides integrated tools for project and idea collaboration, including source control, wikis, document storage, tasks, trackers, file release areas, and discussion forums.

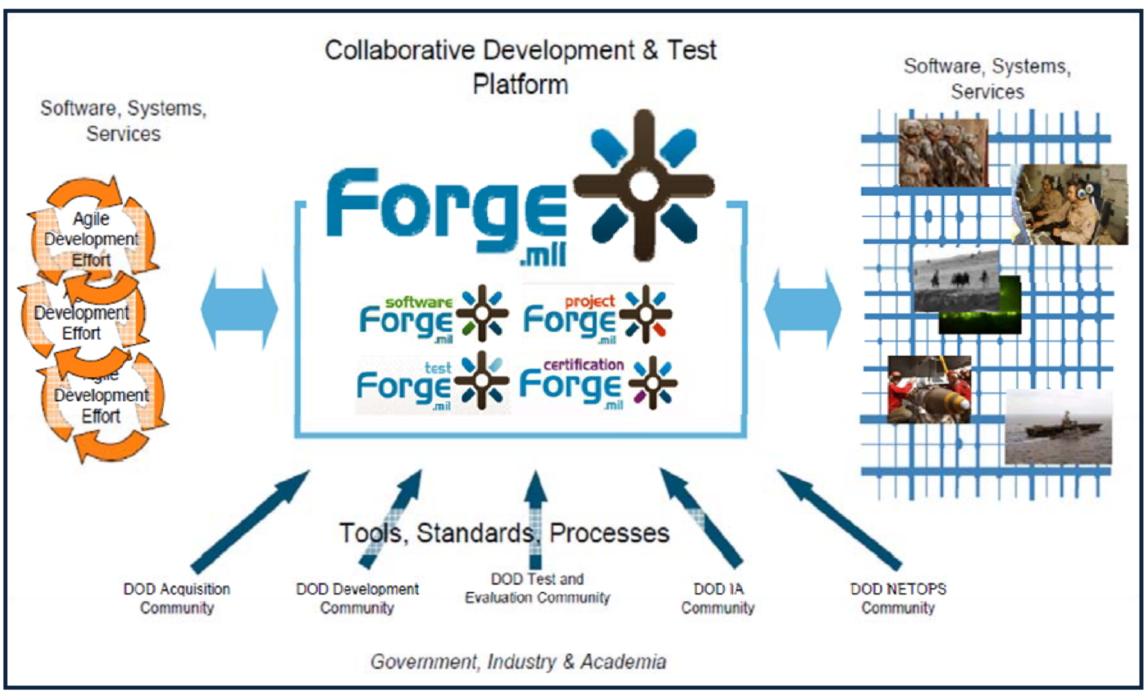

Figure 22. Forge.mil Collaborative Environment (From Defense Information Systems Agency 2009)

The overall goals of the Forge.mil program are to (Defense Information Systems Agency 2009):

- Enable cross-program sharing of software, system components, and services
- Promote early and continuous collaboration among all stakeholder (e.g., developers, material providers, testers, operators, and users) throughout the development life-cycle
- Rapidly deliver effective and efficient development and test capabilities for DoD technology development efforts
- Help protect the operational environment from potentially harmful systems and services
- Encourage modularity so that large programs to be developed, fielded, and operated as a set of independent components that can evolve and mature at their own rates
- Eliminate duplicative testing and improve dependability by adopting common test and evaluation criteria supported by standard testing tools and methods

In keeping with the basic principles of the network-centric top-down approach, Forge.mil allows software developers access to tools that may help build network-centric systems. Usually, developers find it necessary to create their own environments in order to collaborate with other stakeholders of a program. This is a complicated undertaking, especially if project participants are geographically dispersed (Jackson 2009). Forge.mil promotes information sharing with the existence of an on-line repository that can hold software code developed for the government and which can be reused by government according to the original licensing agreement. Often software is available for reuse, but other agencies do not know it is available. Information discovery is facilitated by the requirements defined by COI that software developers belong to.

Joint Vision 2010 (United States Joint Chiefs of Staff 1995) and Joint Vision 2020 (United States Joint Chiefs of Staff 2000) discuss the military's goal to become network-centric and to realize the potential of NCOW. Since the time these DoD-sponsored information guides were published, the DoD has employed several systems that have some capacity to share or discover information. Additionally, a number of current industry developments have provided opportunities that may be useful to the military mission. Each system surveyed in the previous sections contains characteristics and/or contributes to basic principles found in the ISD system. Following the illustration of the NCSE top-down approach and the ISD system described in Figure 12 (Information Sharing leads to Information Discovery), Table 1 clarifies some attributes of the ISD system that are mirrored in current industry developments and DoD implementations.

ISD System Attributes/Provisions	**Examples of Implementations and Industry Developments with Similar Fundamental Characteristics**
- Means to collaborate with others, as needed for the mission	- Collaborative Tools (i.e., DCO)
- Web-enabled functions/services	- Web Portals (i.e., DKO)
- Use of an information sharing platform to share common services needed for the mission	- SOA (i.e., CANES, SOAF)
- Provides platform that assist users to discover information	- Web 2.0
- Allows storage/retrieval of information for users to access/provide information ubiquitously	- Cloud Computing (SaaS, PaaS, IaaS)
- Collaboration is central to information sharing and discovery	- Open Source Software Development (i.e., Forge.mil)
- Use of COIs to facilitate appropriate information for the mission	- DISA NCES Content Discovery and Delivery

- Contribution to the GIG (Network Effect)	- FORCEnet (and other service component implementations)

Table 1. ISD System Attributes/Provisions and Examples of Implementations and Industry Developments with Similar Fundamental Characteristics

Following the functions of other similar collaborative tools, such as the DISA's DCO, the ISD system provides a means to for users to collaborate with others (users, COIs) if needed for the mission. The ISD system's Web-enabled tools/services are akin to those functions found in defense Web portals like DKO, AKO, and NKO. Also, the information sharing platform provides a repository of common services much as SOA provides the architecture for services to be utilized by different clients using the same basic tools.

To discover information, the ISD system supplies an information sharing platform that aids COIs to find information specific their mission. This parallels the recent implementation of Web 2.0 and the view that many users now share, which is: that the WWW is now considered an application that can facilitate their search for information. Similarly, the ISD system shares some of the same basic principles as cloud computing because both allow storage and retrieval of information for users to access and provide information ubiquitously.

The growth of open source software development (i.e., Forge.mil) is also a fundamental principle seen in the ISD system as it highlights that collaboration is central to information sharing and discovery. The use of COIs to facilitate delivery of applicable information to support various missions is comparable to the services provided by the DISA's NCES Content Discovery and Delivery product because both attempt to link the correct publishers and subscribers to mission-applicable information. Finally, resembling FORCEnet (and other similar service component implementations), the ISD system attempts to contribute to the GIG and increase the network effect by connecting users with one another through information.

Table 1 lists several ISD system attributes and provides examples of current implementations and industry developments that display comparable qualities. However, the implementations and developments listed may not be limited to just a

single contribution. Only key contributions are shown to highlight their similarities with the ISD system. The next section discusses how to apply the ISD system model to future network-centric developments.

H. APPLICATION OF THE ISD SYSTEM MODEL

It is important to realize that the concept of the ISD system is not an entirely separate concept from those systems surveyed in preceding sections and it does not offer new functionalities. Rather, the ISD system is a generalized model created using a systems engineering approach and it contains many similarities to the systems discussed previously. Its distinct contribution is that the ISD system model offers a means to map any information system (or sub-system or component), implementation, or concept onto a model that can relate it to the network-centric system. Figure 23 illustrates this notion with several of the systems surveyed earlier in this chapter.

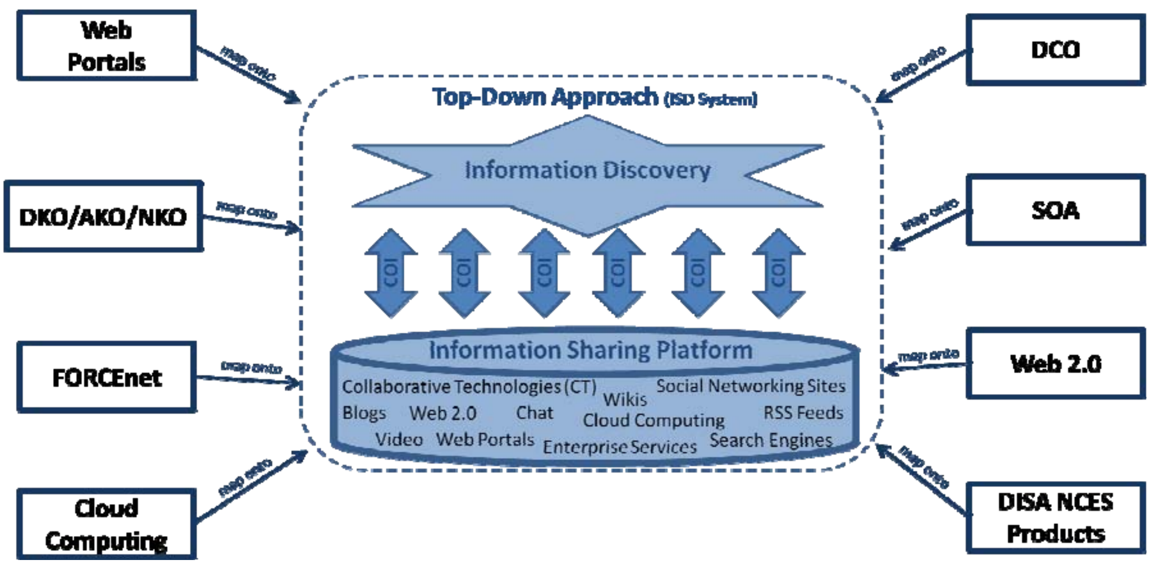

Figure 23. Mapping of Existing DoD Implementations and Industry Developments onto a Generalized ISD System Model

Each of the current implementations and industry developments discussed earlier in this chapter were correlated to the generalized ISD system model. As a specific example, and to illustrate the idea further, the DISA's Forge.mil—an example of a DoD

implementation of the industry concept of open source software development—is mapped to the ISD system model in Figure 24.

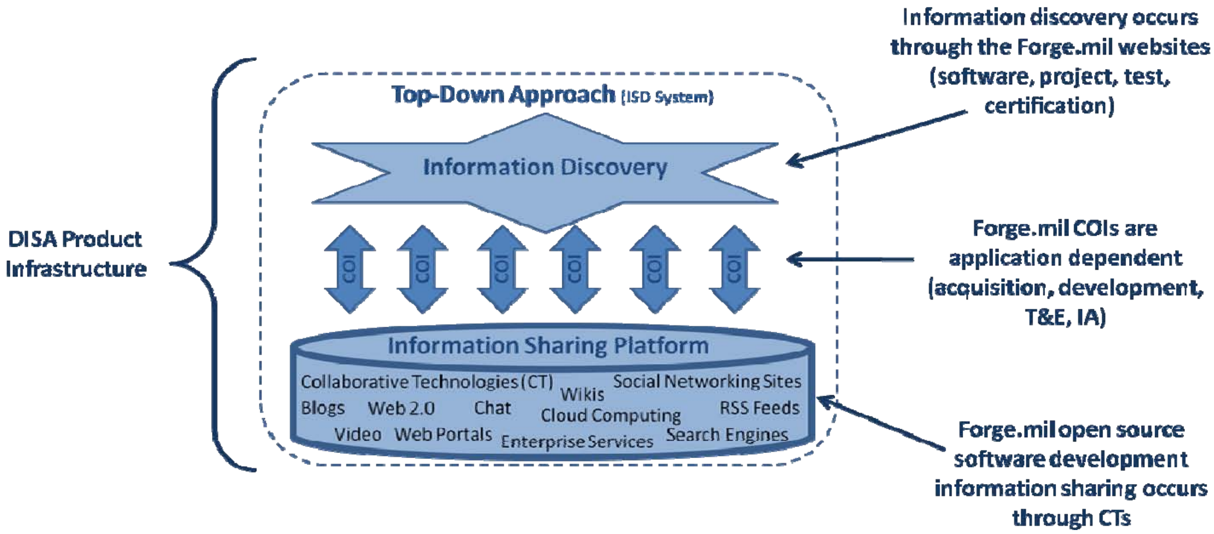

Figure 24. Mapping of Forge.mil (Open Source Software Development) to the ISD System Model

The recent DISA implementation of Forge.mil provides the capability to DoD software developers to share and reuse software. Information sharing occurs primarily through CTs, such as wikis, discussion forums, and file sharing tools. Information shared is dependent upon the specific COI, and is application dependant. There are numerous COIs because the software needed depends on the specific mission and/or the purpose of the COI. Information is discovered by the COIs in any of the four Forge.mil websites (software, project, test, certification) and is software is employed as needed.

Any information system, implementation, or concept can be related to the ISD system model. Furthermore, as there continues to be new developments of information systems and technologies and as additional industry concepts emerge, this model can serve as an aid in understanding how a system contributes to the overall network-centric system by mapping the information sharing and discovery components. This is invaluable from a systems engineering point of view because there is currently no bounded system design for information sharing and discovery in a network-centric system, and no general systems engineering guidance for design and acquisition. With

this ISD system model and mapping, the top-down part of a network-centric system is generalized and bounded and allows mapping of any existing implementation onto it; therefore, this generic ISD System model is used to assist systems engineers in deriving requirements, designing the system structure, and implementing sharing and discovery systems in a network-centric system. Subsequent chapters of this thesis explain this SE process in further detail, with recommended external systems diagram, objectives hierarchy, requirements, and functional architecture.

This chapter gave an overview of the concepts of information sharing and information discovery, and discussed the difference between data, information, and knowledge (Knowledge Hierarchy). The four network-centric approaches necessary to compose a network-centric system were also discussed to reveal that ISD systems reside in the network-centric “top-down” approach. An explanation of how information sharing leads to information discovery was conveyed to show that ISD systems consist of an information sharing platform and are facilitated by COIs that lead the information discovery efforts. A survey of several examples of current DoD ISD systems and relevant ISD trends was conducted to give a contemporary view of the state of the DoD’s acquisition of ISD systems. Finally, an explanation of how the ISD system model can be applied to any information system was discussed. The next chapter explores the importance of requirements in the Systems Engineering (SE) process and further refines the ISD system operational concept by applying the systems engineering process to design of the ISD System. ISD external systems are also discussed to aid in ISD system requirements generation.

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IV. INFORMATION SHARING AND DISCOVERY SYSTEM REQUIREMENTS

It's not enough that we do our best; sometimes we have to do what's required.
– Winston Churchill

This chapter summarizes and presents key products created in the process of deriving requirements for the ISD system. The discussions are separated into four sections. The first section discusses the importance of requirements in the systems engineering process and continues with the operational concept development that was introduced in previous chapters. The second section discusses the external system diagram created for the ISD system which bounds the system design problem and defines system interfaces. The third section introduces the concept of the systems objective hierarchy and addresses fundamental objectives for the ISD system. The fourth section proposes requirements for future ISD systems. The following chapter will further design the ISD system through functional architecture.

A. IMPORTANCE OF REQUIREMENTS IN THE SE PROCESS

The systems engineering process starts with requirements. Clear, well-defined, warranted, and attainable requirements from stakeholders in the system are essential to good design and the subsequent production of a system (Buede 1999, 119). Arriving at the right requirements is not an easy task. It is a continuous goal for systems engineers. If requirements are not well-written, the system risks not being a valuable asset to the stakeholders. Often, the end-user suffers (sometimes disastrous) consequences from the failure to produce an effective system. It is critical that system requirements are as complete as possible because "good" requirements are vital to the successful design and engineering of a system (Buede 1999, 119).

B. EXTRACTING REQUIREMENTS

There are several systems engineering (SE) models and the exact number of phases of the SE process differs based on the SE reference being used. With the exception of specific semantics, the phases are similar no matter which

organization is defining them. DoD Instruction 5000.02, the instruction which establishes the operation of the defense acquisition system, lists the following five life cycle phases (Department of Defense 2008):

- Material Solution Analysis
- Technology Development
- Engineering and Manufacturing Development
- Production & Deployment
- Operations & Support

A system's life cycle is formed with the use of various types of different requirements. In this thesis, we are concerned with developing o*riginating requirements*—or those requirements that are developed in the context of mission requirements and focus on the boundary of the system (Buede 1999, 121). As seen in the Buede's figure (25), requirements are organized hierarchically:

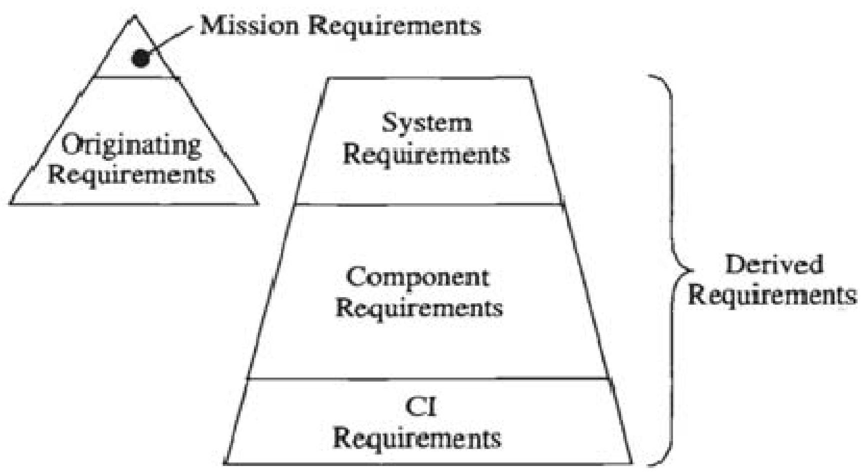

Figure 25. Requirements Hierarchy (From Buede 1999, 122)

Mission Requirements are defined in the context of the super system. In this thesis, the overall mission and the operational concept for ISD systems is summarized in Chapter I, Network Centric Operations and Warfare (NCOW). Originating requirements

fall beneath mission requirements and are not considered derived requirements, as are system requirements, component requirements, and configuration item requirements (Buede 1999, 121).

This study subscribes to the seven functions that Buede presents as necessary for the originating requirements development process. These are:

1. Develop Operational Concept
2. Define system boundary with external systems diagram
3. Develop system objectives hierarchy
4. Develop, analyze, and refine requirements (originating and system)
5. Ensure requirements feasibility
6. Define the qualification system requirements
7. Obtain approval of system documentation

The focus of this study is on the first four of Buede's functions. The preceding chapters began to develop the operational concept for ISD systems through discussions of the role of ISD systems in NCOW. We further refine the operational concept and define the system boundary of ISD systems via use of an external systems diagram. We also develop an ISD system objectives hierarchy to aid in summarizing stakeholders' goals for the system. With the aid of the first three functions, and as seen in Figure 26, Buede's fourth function is realized and originating requirements are developed for ISD systems.

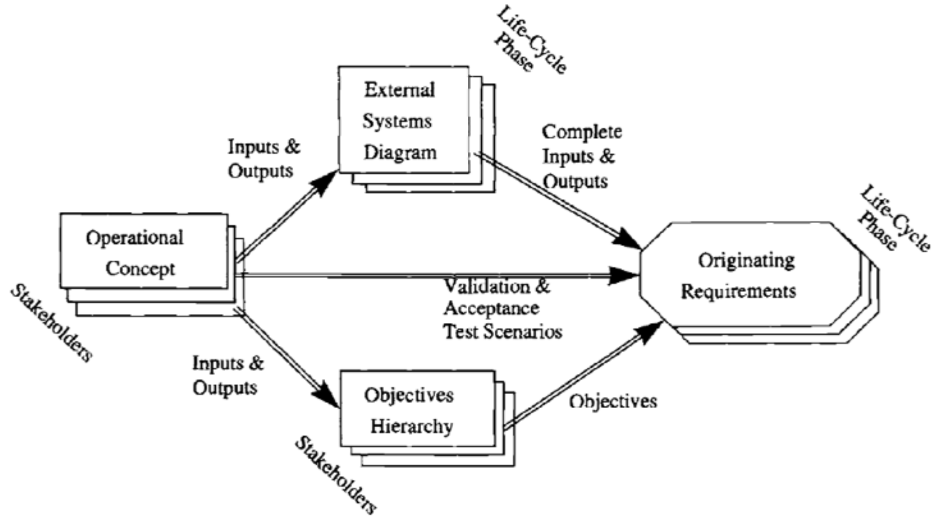

Figure 26. Summary of originating requirements development (From Buede 1999, 159)

The originating requirements identified in this study will aid in future procurement of ISD systems as it will provide acquisition professionals guidelines when identifying capability gaps and deriving requirements. The following chapter will further design the ISD system through functional architecture.

C. IMPORTANCE OF THE OPERATIONAL CONCEPT

According to Buede, the operational concept is a vision of what a system is, in general terms. It is a statement of mission requirements and a description of how the system will be used (Buede 1999, 139). The operational concept provides information about how the system will be employed from the perspective of its stakeholders and states the objectives of systems through a description of how the systems will fit into the stakeholders' world (Buede 1999, 125). It is important to specify that requirements state the "what," but not necessarily "how" requirements will be met. Those inner workings, the *design* of the system, are the responsibility of the engineers who are commissioned to construct the system after requirements have been established.

The need and shared vision for ISD systems were covered substantially in chapters I and II. The overall mission of NCOW requires the capability to share and

discover information. In fact, information sharing plays a significant role in the basic tenets of NCW. To realize the new challenges that the Information Age poses to the 21st century military, it is imperative that the DoD define requirements for systems that bring the information sharing and information discovery capabilities to the DoD. The mission of NCOW requires that we have the resources to enable us to share information seamlessly.

D. OPERATIONAL SCENARIOS

The development of the operational concept started in chapters I-III with exploration into the theory behind full spectrum dominance, information superiority, and how ISD systems contribute to NCOW. To expand on the operational concept development, the following sub-sections present several scenarios that illustrate "real-world" examples of use of an ISD system. Developing scenarios is a preliminary step for systems engineers to facilitate all stakeholders arriving at a universal definition of the system. Scenarios should not focus on how the system is processing inputs and outputs to the system, but instead they should focus on how the system is exchanging information (inputs, outputs) with other systems (Buede 1999, 140).

Scenarios are classified into two categories: those scenarios that describe how a system will be used operationally, and scenarios that describe how a system will be used during other aspects of its lifetime (non-operationally) (Buede 1999, 140). Since this thesis is concerned about having the capability to share and discover information in support of mission operations, this study focuses only scenarios that deal with the NCOW operational mission and does not address the entire life cycle span of the ISD system. Scenarios and mission requirements for the development, manufacturing, training, deployment, refinement, and retirement of the ISD system are not included. The exclusion of non-operational scenarios is not limiting, as there is an abundant amount of operational applications for ISD systems.

1. Operational Scenario One: Combat Information Center Watch Officer Deployed on a Cruiser in the Persian Gulf

A Combat Information Center Watch Officer (CICWO) deployed on a cruiser in the Persian Gulf is standing the 0400-0700 watch. In preparation to turnover to oncoming watchstanders, and to prepare for the daily morning brief to the Commanding Officer, the CICWO logs onto a secure Web portal to gather information about the events that occurred during her watch and events that will affect the Plan of the Day (POD). The Web portal, which is an element of the information sharing platform (Figure 12), offers her a large quantity of information about the events that will affect her command. The CICWO belongs to several COIs that pertain to her mission areas—intelligence, strike operations, 5th Fleet information, surface warfare operations—therefore, she is able to subscribe to information that is only relevant to her work.

The CICWO pulls the following information:

- News highlights from current events occurring in the United States and around the world
- Intelligence Reports pertaining to the United States Central Command Area of Responsibility (AOR) and the Commander, U.S. 5th Fleet AOR
- A copy of the Carrier Strike Group POD, including the carrier flight operations plan
- The proposed transit plan of the oiler the cruiser intends to conduct a logistics replenishment with later in the afternoon

2. Operational Scenario Two: Unified Combatant Command Desk Officer Preparing a Staffing Request

A Unified Combatant Command desk officer has received direction from his superior officer to prepare a brief in preparation for a partner nation's senior official's visit. The desk officer has no experience in preparing this type of brief and is not given clarifying direction about his tasking. The desk officer refers to a host of information sharing tool/services (Figure 12) that may assist him with his new assignment. He logs

into a DoD personnel information website and, through his membership in a similar COI, discovers contact information of a counterpart at another Unified Combatant Command.

After making initial contact with his counterpart, the desk officer discovers that a similar brief was given to the same partner nation's senior official, and it was a successful presentation. The desk officer requests that his counterpart share the outline of his brief with him, so that he may duplicate the format for his own brief. Both officers, as well as a staff representative for the partner nation, meet via a Web-enabled collaborative technology to video teleconference and view the presentation together. The colleagues are able to share files with the use of a file-sharing tool available on the CT, as well. During the online meeting, the desk officer receives information about how to make his brief successful. His counterpart shares information about the aspects of the presentation that were well-received and the parts that were not favorable. The partner nation's representative is also able to add insightful suggestions about what presentation topics his senior official will be interested in.

3. Operational Scenario Three: Commander of Small Boat Security Unit Facing Immediate Threat

The commander of small boat security unit for a naval installation is facing an immediate threat to the perimeter of the base. The suspicious watercraft his unit has been pursing is able to evade them in the darkness of the night, and the unit personnel have reason to believe that an unauthorized enemy diver has penetrated the base perimeter, as well.

While onboard his patrol boat, the unit commander uses his handheld laptop to access an information sharing platform tool (Figure 12) and log in to the naval installation's security Web portal. While attempting to relocate the suspicious watercraft and diver, he views raw data sent from various sensors located around the installation. Since he and his team belong to a maritime defense activity security COI, they are able to review (discover) live video streams from docked ship hulls and from cameras attached

to the underside of multiple piers. They have access to alerts from motion sensors in the immediate vicinity, and are able to pull information from audio sensors that have sensed abnormal background noise.

The team's membership in local law enforcement COIs allows them to discover information about how to contact local security officials and gain access to the information in their database and sensors. The fusion of this information allows the commander to deduce the correct location of the enemy watercraft and the small boat security unit is able to apprehend the suspects and the diver.

E. DEPICTION OF THE ISD SYSTEM

The ISD system is a human-designed system that consists not only of the system itself, but of internal systems and external systems (that affect and are affected by the system). All of these systems lie within a context. The context contains other systems that affect, but are not affected by, the ISD system.

Figure 27 illustrates the ISD system and its relationship with other systems. The system is comprised of several internal systems that interact to form ISD system, these are: Processor, Support Personnel, Data Storage, Server, Database, and Computer Network. External systems, located within the dotted line, are a set of entities that interact with the ISD system via the system's external interfaces (Buede 1999, 38). For the ISD system, the external systems are defined as: Bottom-Up System, Middle Approach System, User, and Side View System. External systems can impact the ISD system; however, the ISD system definitely impacts the external systems. All of the ISD system outputs flow to the external systems. Inputs to the system may come from the context entities or from the external systems.

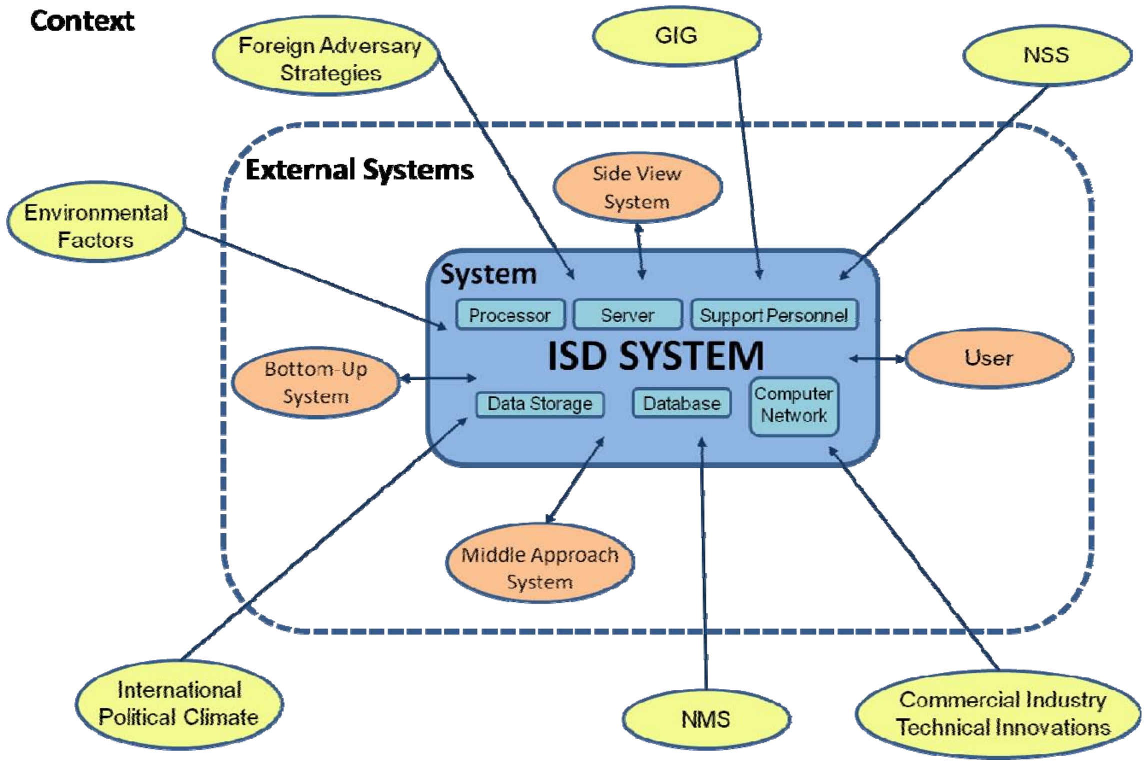

Figure 27. Depiction of an ISD system

The context of the ISD system contains the set of entities that may impact the system, but cannot be impacted by the system. The context consists of the: International Political Climate, National Military Strategy (NMS), Commercial Industry Technical Innovations, National Security Strategy (NSS), GIG, Foreign Adversary Strategies, and Environmental Factors systems.

F. EXTERNAL SYSTEMS DIAGRAM

To define the system boundaries, and to establish assumptions made for the design of the system, an external systems diagram is presented to show the boundaries of an ISD system. Every sub-system and component located on the inside of the system boundary is considered part of the system and is subject to change. Likewise, everything located on the outside of the system cannot be changed. The systems engineer is responsible for facilitating the process of establishing boundaries, which are defined by the stakeholders in the system with input from the procurers of the system (Buede 1999, 144). More importantly, the external systems diagram illustrates the interactions between

the ISD system and external systems. Again, at this point in the ISD life cycle, the focus should be on the inputs and outputs of the ISD system and not necessarily on the internal workings of the system presented. It is important only to highlight the interactions our system has with other systems.

Buede defines external systems as "entities that interact with the system via the system's external interfaces" (Buede 1999, 38). In the case of the ISD system, the following external systems and system functions exist:

External Systems	System Functions
Bottom-Up System	Provide smart sensor network
Middle Approach System (Smart push/pull)	Provide the ability to publish/subscribe to information
Users	Receive/process information and apply to mission
Side View System (Disadvantaged User)	Provide tactical smart information at the edge

Table 2. ISD system external systems and functions

Note that each of the ISD system’s external systems correspond to the network-centric approaches introduced in Figure 11. From a systems engineering perspective, a network-centric system must include all four approaches/systems. Therefore, the top-down (ISD) system, bottom-up system, middle approach system (smart push/pull), side view system (disadvantaged user), and users are considered systems, in the network-centric system of systems.

In Figure 28, interactions between the ISD system and its external systems are traced for use during the operational phase of system. Inputs to the top-down (ISD) system (red lines) come from each of the external systems. The bottom-up system provides raw information and data that will be further processed in the top-down (ISD) system. Simultaneously, the ISD system pulls data and information from the middle approach system (smart push/pull). The side view (disadvantaged user) and user systems provide updated, corrected, and/or new data and information to the ISD system for further filtering and processing.

The top-down (ISD) system provides several outputs (green lines) to its external systems, as well. It provides pertinent information to the side view (disadvantaged user) and user systems for use in their respective mission areas. The top-down (ISD) system also supplies updated, corrected, and/or new data and information to the bottom-up system for use in updates to its sensor network. Finally, the ISD system pushes data and information to the middle approach system (smart push/pull).

Additionally, there are several constraints (dotted lines) on all systems in this network-centric system of systems. These include, but are not limited to: data storage, computing network infrastructure support, security, information management, environmental conditions, and bandwidth.

The interactions (inputs, outputs, constraints) between the top-down (ISD) system and its external systems will be used to help derive requirements for future ISD systems.

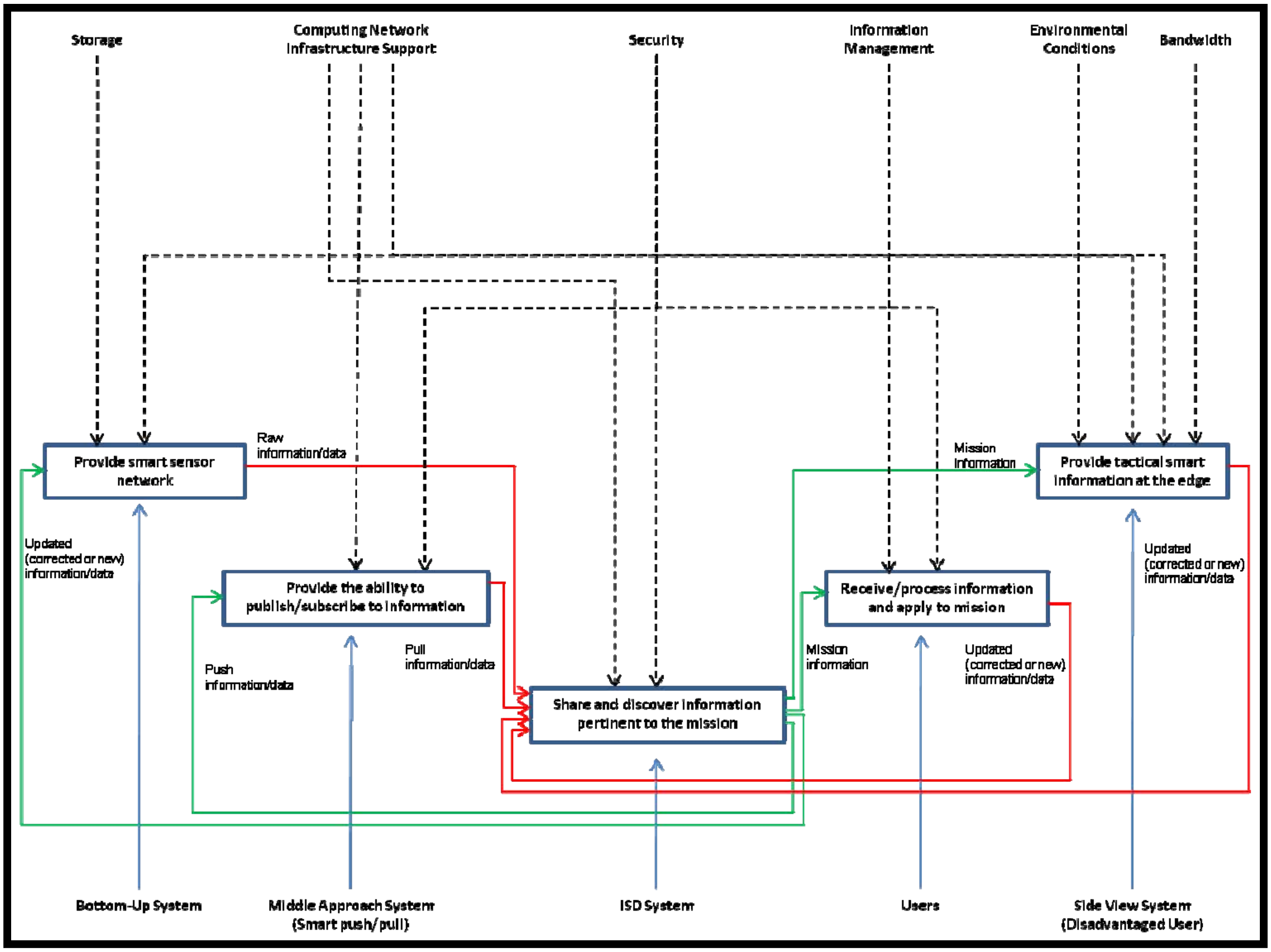

Figure 28. ISD System External Systems Diagram

G. SYSTEMS OBJECTIVES HIERARCHY

Another step in the effort to derive requirements for the ISD system is to compose an objectives hierarchy. The objectives hierarchy summarizes the goals "that are important to the systems stakeholders in a value sense." This means that stakeholders should be able to pay to achieve increased performance, or decreased cost, as it pertains to the attributes cited in the objectives hierarchy (Buede 1999, 147). Some examples of the types of objectives that may be considered are: cost objectives, performance objectives, technical performance objectives, suitability objectives, schedule objectives, and risk objectives.

In the acquisition of the ISD system—a system that connects information sources and enables collaboration and information exchange to facilitate meeting critical mission requirements—our supporting objectives are to minimize the overall cost of the system and to maximize system performance. The systems objectives hierarchy, shown in Figure 29, illustrates the ISD systems' supporting objectives and introduces subdivisions that contribute to the overall objective. Cost, for example, is divided into three types of expenditures: development, maintenance, and other life cycle costs such as operations and support and system disposal. System performance is composed of three attributes: security, functionality, and quality of the information. These attributes are further decomposed to assess other supporting objectives that contribute to the overall goal of the ISD system.

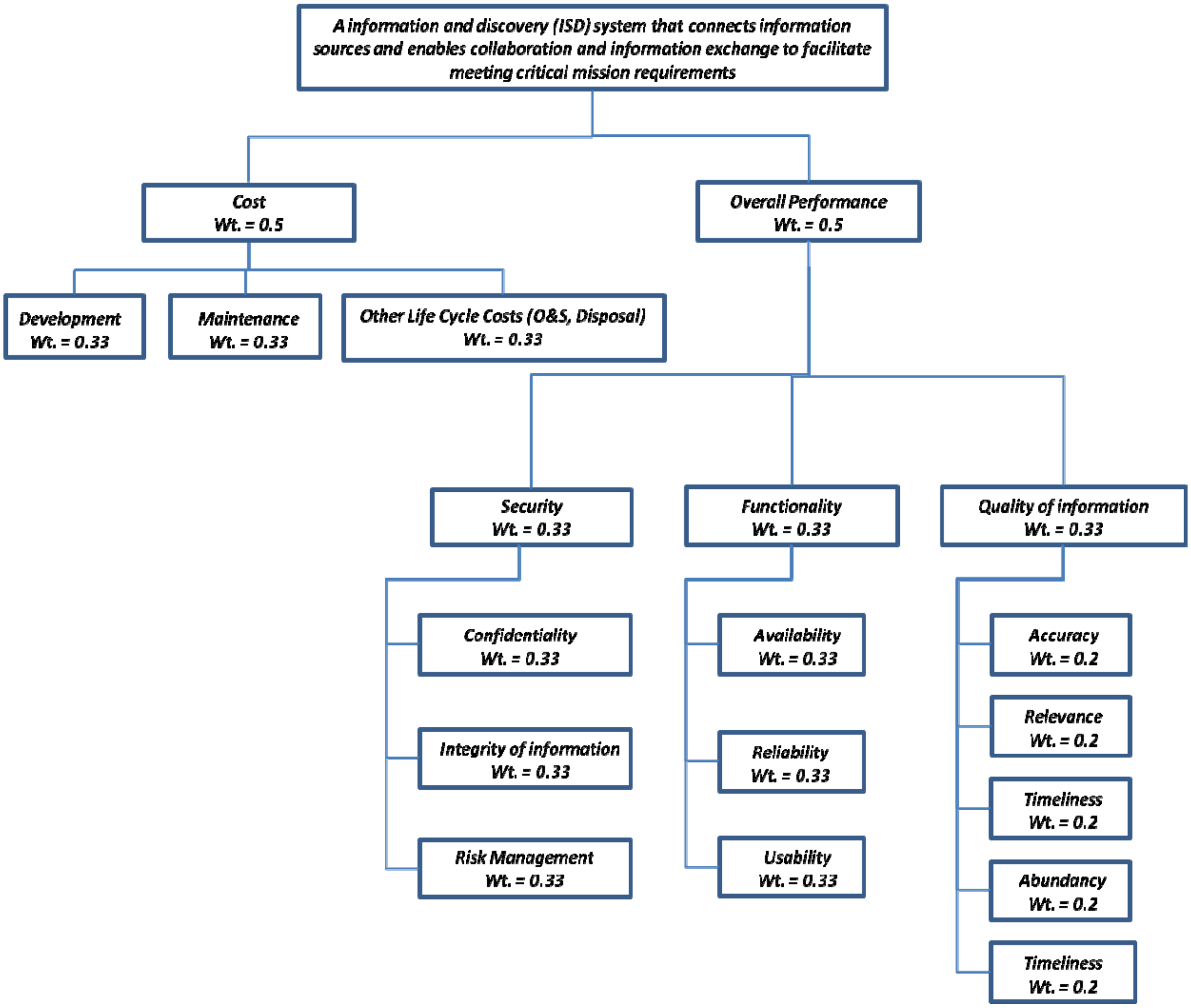

Figure 29. ISD System Objectives Hierarchy

The purpose of the systems objectives hierarchy is to organize the "trade-offs" that need to be considered when deriving requirements for the ISD system. Since this study does not endorse a particular ISD system—and weights are highly dependent upon the mission area and unique constraints of a situation—the supporting system objectives and weights listed in Figure 29 are normalized. These system objectives are generalized and equally-weighted, therefore they can be applied to any ISD system and should be considered a template for further objectives to consider in specific ISD systems where weights may be adjusted accordingly.

H. TYPES OF REQUIREMENTS

Defining requirements for an ISD system is based on information gathered from creating the operational concept development, the external systems diagram, and the objectives hierarchy. According to Buede, there are four requirement categories: input/output, system-wide and technology, trade-off, and qualification.

1. Input/Output Requirements

Input/output requirements are requirements based on "the basis of the inputs, controls, and outputs of the system" (Buede 1999, 153). When developing this set of requirements, the primary tool used is the external systems diagram because this product allows a view of system boundaries and interactions with external systems. Also, it is important to address the context (or environment) that the system is being used in these requirements.

2. System-Wide and Technology Requirements

System-wide and technology requirements pertain to the entire system, and are not limited to just interactions with external systems. These requirements often belong to more than just one requirement category, but can be distinguished this type of requirement because knowledge of the entire systems is required to determine if the requirement has been met (Buede 1999, 154). The objectives hierarchy aids in establishing these types of requirements and typically, every system-wide requirement should be addressed in this product.

3. Trade-off Requirements

Trade-off requirements are requirements that are based entirely on the stakeholders in the system. Each set of stakeholders possesses value judgments pertaining to the cost, schedule, and performance of the system. Depending on the stakeholder it may be easy to determine the value judgments; however, it is important to ascertain a good representation of all stakeholders' judgments regarding the system.

4. Qualification Requirements

Qualification requirements contain four elements for the systems life cycle: observance, verification plan, validation plan, and acceptance plan. Each of these phases has specific qualification criteria that need to be met. The observance phase pertains to how each of the input/output and system-wide requirements will be met. The verification plan phase addresses data that is used to ascertain if the system meets the expectations of system design. The validation plan data ensures that the system meets the goals of the originating requirements. The acceptance plan outlines data that will determine if the system is satisfactory for the users' needs (Buede 1999, 156).

I. ISD SYSTEM REQUIREMENTS

Like the ISD system operational concept scenario development, the focus of this study is on the operational aspect ISD systems and on the first phases of the system engineering process (system definition and concept definition). Since this is a conceptual thesis and there is no specific ISD system being addressed. Therefore, the following sub-sections list recommended high-level requirements and contain little detail. It is assumed that the ISD system acquirers will be able to identify specific needs depending on the mission type and regard these requirements as an outline for their own systems.

1.0 ISD System Originating Requirements

1.1 Input/Output Requirements

1.1.1 Input requirements for operation

1.1.1.1 The ISD system shall receive raw data and information from the bottom-up system.

1.1.1.2 The ISD system shall pull information from the middle approach system (smart push/pull).

1.1.1.3 The ISD system shall receive updated, new, and/or corrected information from the side view system (disadvantaged user).

1.1.1.4 The ISD system shall receive updated, new, and/or corrected information from the user system.

1.1.2 Output requirements for operation

1.1.2.1 The ISD system shall push data and information to the middle approach system (smart push/pull).

1.1.2.2 The ISD system shall provide updated, new, and/or corrected information to the bottom-up system.

1.1.2.3 The ISD system shall provide mission information to the user system.

1.1.2.4 The ISD system shall provide mission information to the side view system (disadvantaged user).

1.2 External Interface Requirements

1.2.1 The ISD system shall interface with the bottom-up system.

1.2.2 The ISD system shall interface with the middle approach system (smart push/pull).

1.2.3 The ISD system shall interface with the user system.

1.2.4 The ISD system shall interface with the side view system (disadvantaged user).

1.3 System-wide and Technology Requirements

1.3.1 The ISD system shall provide a means to connect information sources, enable collaboration, and promote information exchange to facilitate meeting mission requirements.

1.3.2 The ISD system shall be designed to promote accessibility to information based on the user need, mission, and purpose of information sharing and information discovery.

1.3.3 The ISD system shall be equipped with components that include a network backbone, software, and hardware necessary to process, receive, and provide information as defined by the user.

1.3.4 The ISD system shall organize raw data and information received in a logical format that promotes user-friendliness.

1.3.5 The ISD system shall continuously renew existing information with updated, new, and/or corrected so user(s) have access to the most current information.

1.3.6 The ISD system shall comply with the designated computer network and network infrastructure protocol.

1.3.7 The ISD system shall have and provide, when accessed, informal training for new users.

1.3.8 The ISD system shall comply with the designated communications protocols.

1.3.9 The ISD system shall ensure information confidentiality, integrity, and availability is preserved through use of security tools designated by the appropriate directives.

1.4 Trade-off Requirements

1.4.1 The ISD system shall incorporate cost and performance as part of the tradeoff design.

1.4.2 The ISD system shall incorporate security, functionality, and quality as parts of the performance tradeoff design.

1.4.3 The ISD system shall incorporate development, maintenance, and other life cycle costs (such as operations and support and system disposal) as parts of the cost tradeoff design.

1.4.4 The ISD system shall incorporate bandwidth, infrastructure support, network strength, technological advances, and environment as part of the overall system tradeoff design.

1.5 Qualification Requirements

1.5.1 The qualification system for the ISD system shall prove information sharing and information discovery pertinent to the mission.

1.5.2 The qualification system for the ISD system shall prove accessibility for COIs seeking to mission critical information.

1.5.3 The qualification system for the ISD system shall prove that COIs will dictate information discovery.

1.5.4 The qualification system for the ISD system shall prove value to the NCOW mission.

This chapter summarized and presented key products created in the systems engineering process of deriving requirements for the ISD system. The importance of requirements was discussed and the operational concept further developed to highlight the role that ISD systems play in the NCOW mission. An external system diagram was presented to bound the ISD system design problem and define system interfaces. Also, a systems objective hierarchy addressed fundamental objectives for the ISD system. Finally, the last section in this chapter proposed originating requirements for future ISD systems.

The next chapter will continue with the design by developing a functional architecture for the ISD system.

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V. INFORMATION SHARING AND DISCOVERY SYSTEM FUNCTIONAL ARCHITECTURE

Each new situation requires a new architecture.
– Jean Nouvel

This chapter summarizes and presents key products created in the process of developing a functional architecture for the ISD system. The discussions are separated into four sections. The first section discusses the requirement and process of developing the functional architecture of a system. The second section discusses the functions identified for the ISD system and presents the system functional hierarchy. The third section presents the development of the ISD system functional decompositions. The fourth section introduces a requirements traceability matrix to track requirements to elements of the ISD system's functional architecture.

A. THE ROLE OF FUNCTIONAL ARCHITECTURE IN AN ISD SYSTEM

The functional architecture of a system characterizes what a system will do. It defines system functions and the information that flows between them (Buede 1999, 19). It is important for a systems engineer to spend an adequate amount of time thinking about the functions of the system and the relationship the activities have with one another because these interactions will ultimately dictate how successful the system is for the end-user. Defining the functions the system needs to perform is as important as the physical design of the system. In the process of architecting a system, the physical architecture and the functional architecture are both equally critical in eventually producing the operational architecture of the system (Buede 1999, 20). Figure 30 illustrates the relationship the functional architecture and the physical architecture have in combining to produce a meaningful operational architecture:

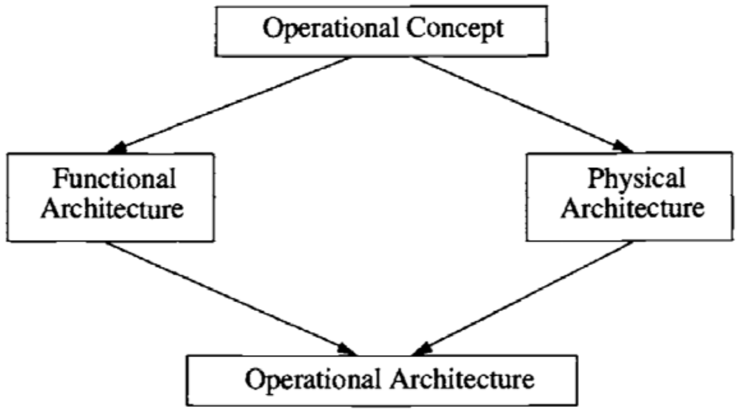

Figure 30. Architecture development in the engineering of a system (From Buede 1999, 20)

Due to the scope of this research, and the broad nature of ISD systems, this study identifies only critical aspects of the functional architecture. The physical architecture and operational architecture of the ISD system is left for continued research on the topic and is beyond the range of this thesis. The physical architecture is highly dependent on the mission of the organization designing it and specific details about the system type is left for further studies. According to Buede, the functional architecture may be revised several times as the operational architecture is being finalized. This study's goal is to submit an initial and conceptual draft of a functional architecture that can eventually be combined with a physical architecture to produce the operational architecture of the ISD system.

B. FUNCTIONAL ARCHITECTURE OF AN ISD SYSTEM

A *function* is a process that takes inputs in and transforms these inputs into outputs (Buede 1999, 178). Each function has criteria for activating and for exiting the transformation—the change from one state to another—that is occurring. Buede states that a functional architecture can be defined at several levels of detail. The most common, however, is "a logical architecture that defines what the system must do, a decomposition of the system's top-level function" (Buede 1999, 179). This functional architecture is most often represented as a directed tree.

Chapters II and III introduced the ISD system operational concept, and scenarios were presented to introduce the system and its objectives. The early stages in the life cycle introduced system functions that where simplistic and not well-defined. However, designing the functional architecture is characterized as the point in the system design process where "functionalities are created by shining a light into the black box" introduced earlier (Buede 1999, 180). The functionalities of the system are made even clearer with functional decomposition and/or composition.

C. ISD SYSTEM FUNCTIONS

1. ISD System Top-Level Functions

The ISD system is unique because it is a system that may encompass several different services (Web portal, wiki, Web-enabled CT, etc.). These tools, elements in the information sharing platform (Figure 12), contribute the same basic functionalities to the ISD system. The information sharing platform permits COIs to discover information that will enable them to meet mission requirements.

Regardless of the physical form of the ISD system, its essential objective is to share information so that users may discover information that will aid in successful completion of their mission. Figure 31 illustrates the top-level functions defined for the ISD system. (An ISD system full functional decomposition is presented in Figure 39, following explanations of each top-level function hierarchy.)

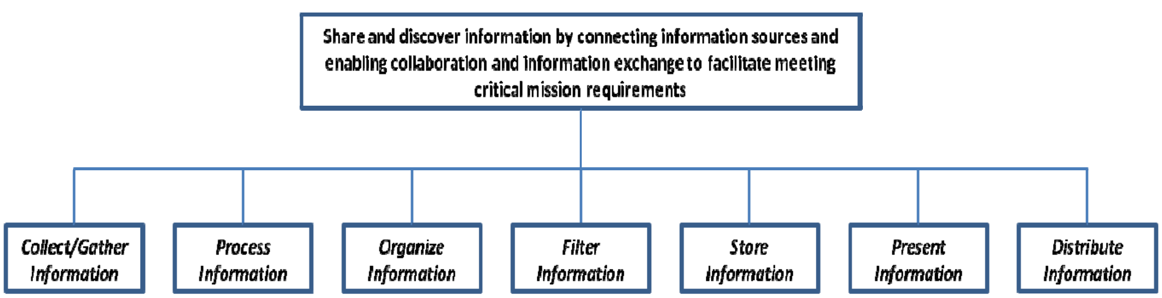

Figure 31. Top-level ISD System Functions

The functional aspects of the ISD system were derived after focusing on the system's objectives recalled from Chapter IV (Buede 1999, 187). Especially in defining top-level functions of a system, it is critical that a systems engineer use the overall system objectives as guide. This will enable the final product to be more efficient, and valuable, for the end-user.

D. ISD SYSTEM FUNCTIONAL DECOMPOSITION

The ISD system consists of seven top-level functions that aid in the overall objective to share and discover information. These functions enable the system to communicate information pertinent to the mission of the end-users, they are: *Collect/Gather Information*, *Process Information*, *Organize Information*, *Filter Information Store Information*, *Present/Display Information*, and *Distribute Information*.

1. Collect/Gather Information

The collection and gathering of data or information is a critical, initial function for the ISD system. This activity results in the ability of the other functions to contribute to the system. It involves the process of gathering data and collecting information for the system to work with and process accordingly.

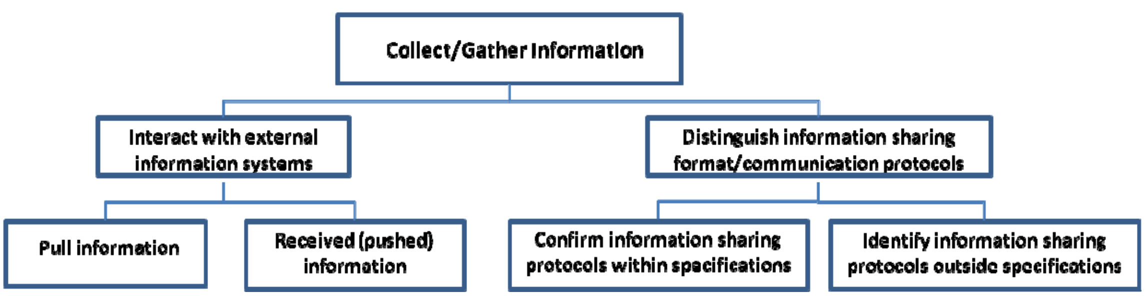

Figure 32. Functional Decomposition: Collect/Gather Information

The second level of the functional decomposition is comprised of the activity of the system interacting with other external systems to gather information. This level of the decomposition is also concerned with differentiating the format, or communication protocol, of the information that is shared.

The third level of decomposition deals with the ISD system pulling information from various sources, such as various standalone databases and/or knowledgeable Web-based storage repositories. It also involves the process of receiving information (information push) from other sources—sources that are themselves, sharing information and dispersing it. Communication protocol is vitally important to the collection/gathering function because information is of no use to the ISD system if it is not in a format that is understandable to the system and the COIs.

2. Process Information

The function of processing information provides the widest scope of the functions of the ISD system because it involves the processes of information categorization and conversion. These are important activities for the ISD system because they will enable the system to fulfill further COIs requirements and requests for future information from end-users. If the data received is not able to be converted into a format that is accessible by the system, it cannot be presented to users for mission requirements. Likewise, if data received is not classified correctly, then it will be insignificant to the COI's mission. The second level of the *Process Information* functional decomposition addresses information categorization and conversion.

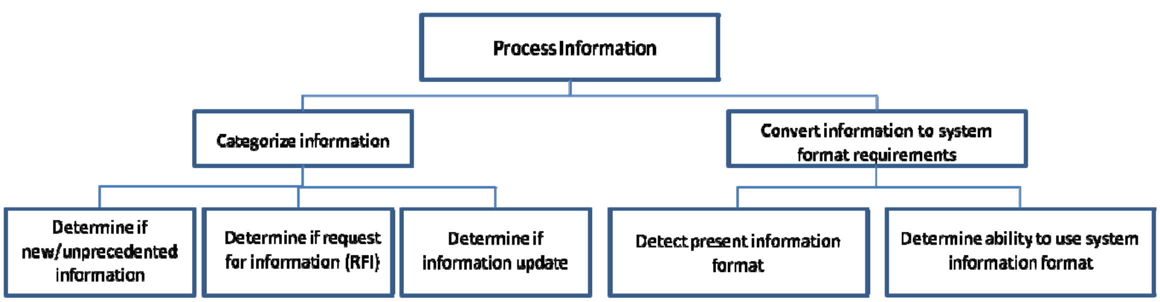

Figure 33. Functional Decomposition: Process Information

The third level of the decomposition further catalogs information into subsets. Information is examined to determine if it is new/unprecedented information, a request for information (RFI), or an update to information that already exists in the ISD system. Data format is also detected to determine if the information is able to be converted to the ISD system format.

3. Organize Information

The function *Organize Information* is concerned with the classification of collected information and determining how data will be further processed.

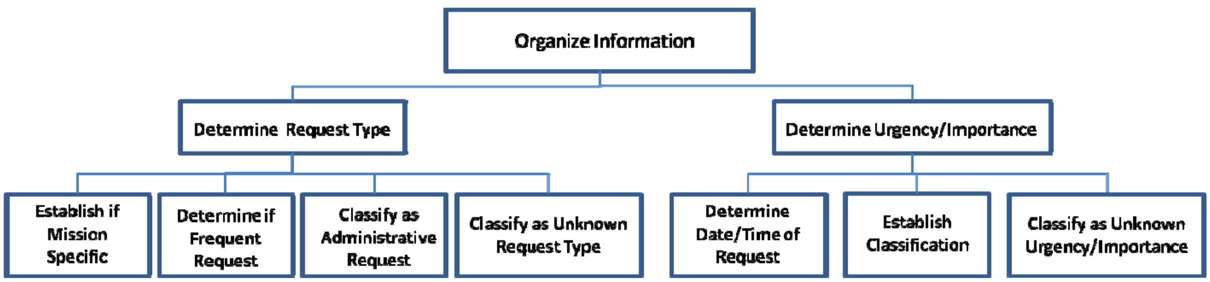

Figure 34. Functional Decomposition: Organize Information

The second-level of the functional decomposition determines the type of information request that is presented. Further decomposition establishes if the requests pertains to a mission, determines if this is data that is frequently requested, classifies the request as administrative if the information pertains to the functions of the ISD system only, or will classify the request type as unknown if there is no appropriate categorization.

Another second-level decomposition will determine the urgency and importance of the information. The third-level of this decomposition illustrates that the system determines the date and time of the request, establishes the classification of the information, or classifies the importance as unknown.

4. Filter Information

The *Filter Information* function determines the future course of information in the ISD system. This is a critical function of the system as it will alleviate much of the risk the system has for accepting unwarranted, erroneous, and high-security risk information that may have been collected earlier unassumingly. This function disposes of information that may pose a risk to the ISD system, or will cause the system's content to become discredited with wrong information. For the data which poses little security risk, and originates from credible information sources, this function allows the information to flow (to continue processing in the system).

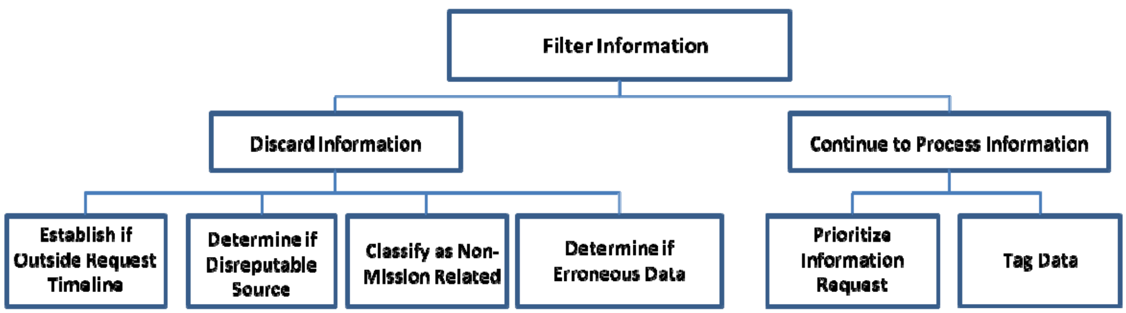

Figure 35. Functional Decomposition: Filter Information

In the second-level of the decomposition, data can be discarded, or continue to be processed by the ISD system. The further decomposition of information to be discarded, establishes if the information request is outside the prescribed timeline, if the data is from a disreputable source, if the data is non-mission related, or if the data is erroneous. Information that proceeds for further processing is prioritized and tagged.

5. Store Information

The *Store Information* function allows the ISD system to store information that may be used for future COI RFIs, statistical data, or as a baseline for comparison to newly arriving data.

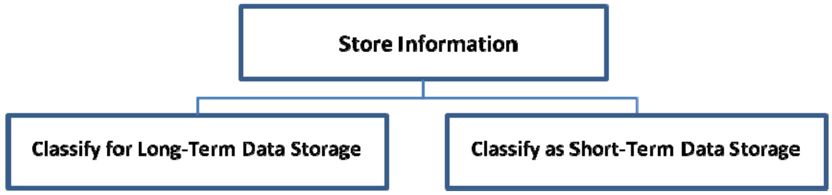

Figure 36. Functional Decomposition: Collect/Gather Information

This function decomposes to a second level only and stores information based on if it is needed for long-term information requirements, or short-term RFIs.

6. Present Information

The top-level function *Present Information* is a critical activity of the ISD system as it affects the end-user more than any other top-level function. This function is essential for the human component (of the system receiving data) to discover information in a format that they can comprehend clearly. Since the ISD system is a networked and/or Web-based system, discovered information can be presented in two primary ways: visually and via auditory signals. This function enables the communication of data from the ISD system to the humans. The COI constituents, the human users, will use the discovered information to make crucial decisions about their mission.

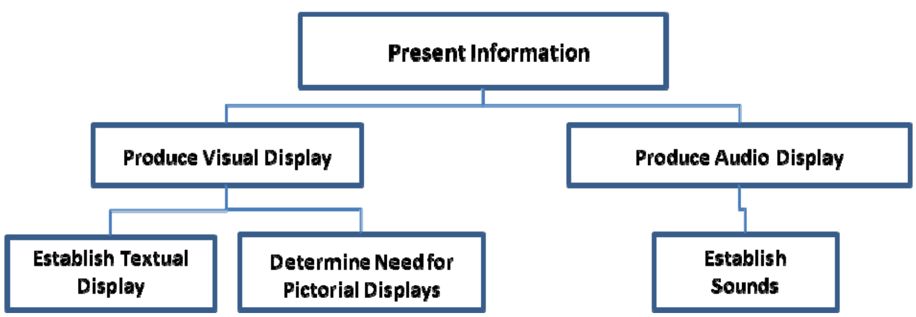

Figure 37. Functional Decomposition: Collect/Gather Information

The second-level of the *Present Information* function produces visual and auditory information for the users. Further decomposition of the visual display establishes the correct textual and picture displays to represent the information that needs to be conveyed. Sounds are also established to portray the audio signals that need to be shared.

7. Distribute Information

The *Distribute Information* function is the seventh and final top-level function for the ISD system. This function is concerned with the activities that determine which information to push or publish. Information to be published is converted to an output format specific to the ISD system. Also, information that is a recent version of stored data is used to update the information repository, as well as other similar information sources and systems.

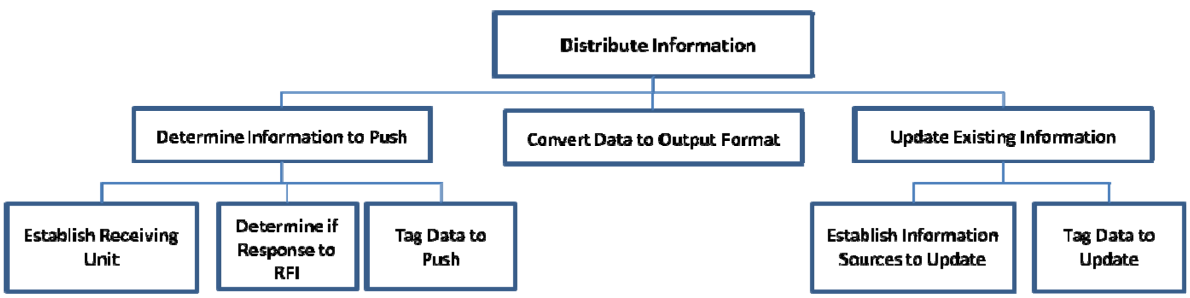

Figure 38. Functional Decomposition: Collect/Gather Information

The second-level decomposition of the *Distribute Information* function determines if information is qualified to be published to users. Data is converted to an output format and also used to update existing information stored in the ISD system. Further decomposition establishes the correct receiving unit and categorizes if the distributed information is in response to an RFI. Data is also tagged to according to the specific ISD system's specifications. If it is established that the data is necessary to update older (inaccurate) information, information sources are identified.

8. Full Functional Decomposition

Figure 39, the ISD system full functional decomposition, illustrates the top three levels of the system's functional decomposition. The top level starts with the ISD system's primary functions and then partitions the functions into several sub-functions.

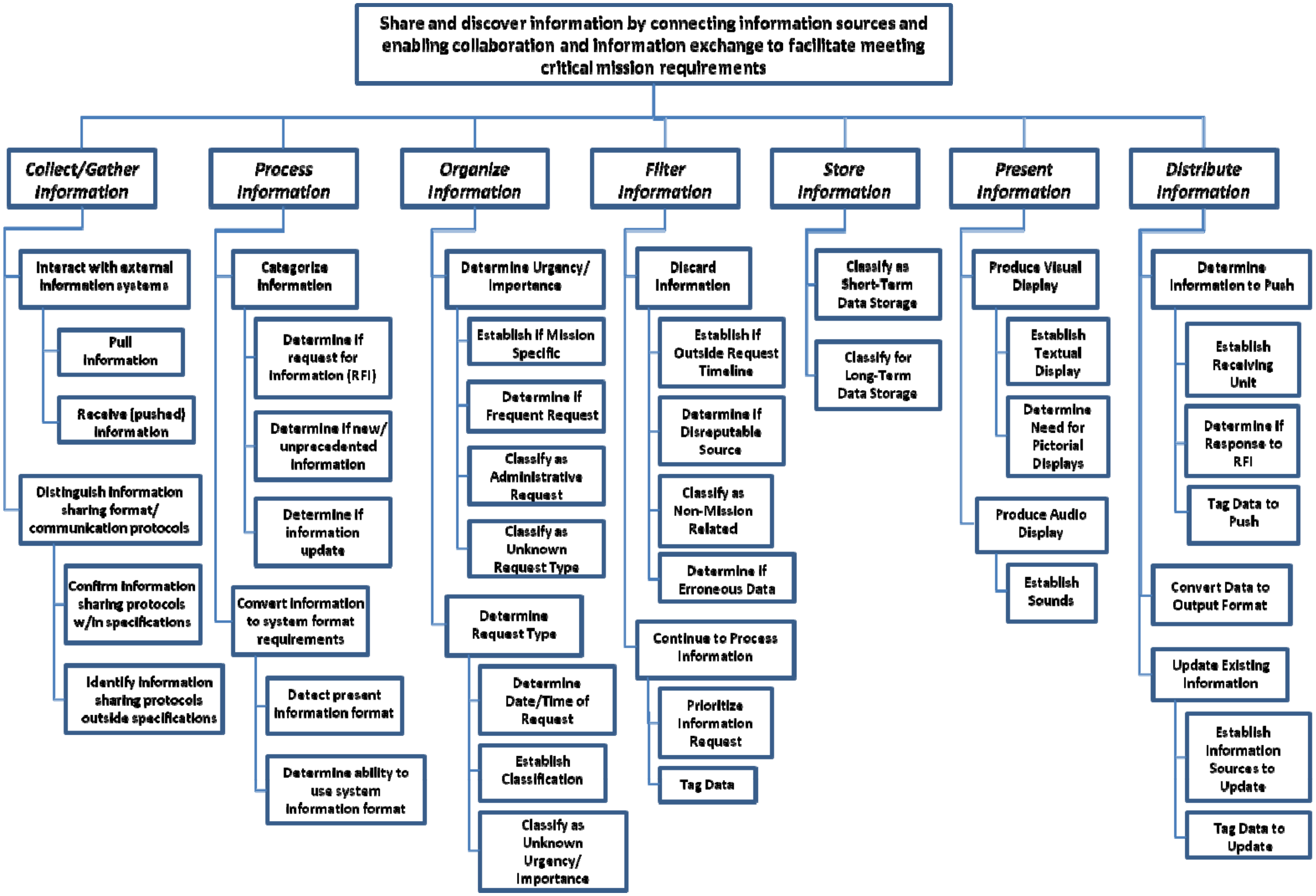

Figure 39. ISD System Full Functional Decomposition

E. TRACING REQUIREMENTS FOR THE ISD SYSTEM

A Requirements Traceability Matrix (RTM) was the final step in producing the functional architecture of the ISD system. An RTM is an aid to ensure that the system's requirements can be traced to the system's functions, and vice versa. The traceability of functions and requirements provides a "valuable consistency check" (Buede 1999, 210) for the systems engineer to ensure that the system's functional design is meeting the goals of the stakeholders. The functional decomposition of each top-level function was used to verify that requirements were met.

Since the concept of the ISD system does not include the specificities of the physical architecture (hardware design, etc.), it is important to realize that the requirements and functions for the specific ISD system will vary widely. The mission set, itself, will incite many more comprehensive requirements. This study has endeavored to produce those requirements and functions that will be commonly found in *any* ISD system, however, the ultimate version will depend on the stakeholders in the actual process. Also, several iterations of the system requirements and architectures (functional, physical, operational) will transpire. The process to design the system will undergo many transformations, and require many versions of the products presented in this study.

The RTM is divided into six sub-sections. Each section represents different types of requirements. Recall that the types of requirements we have introduced for the ISD system are: input/output, system-wide and technology, trade-off, and qualification requirements.

1. Requirements Traceability Matrix–Input Requirements

Functions	1.1.1. Input Requirements			
	1.1.1.1. The ISD system shall receive raw data and information from the bottom-up system	1.1.1.2. The ISD system shall pull information from the middle approach system (smart push/pull).	1.1.1.3. The ISD system shall receive updated, new, and/or corrected information from the side view system (disadvantaged user).	1.1.1.4. The ISD system shall receive updated, new, and/or corrected information from the user system.
Collect/Gather Information	X	X	X	X
Interact with external information systems		X		
·Pull information	X		X	X
·Receive (pushed) information	X		X	X
Distinguish information sharing format/communication protocols	X	X	X	X
·Confirm information sharing protocols within specifications	X	X	X	X
·Identify information sharing protocols outside specifications	X	X	X	X
Process Information				
Categorize information				
·Determine if new/unprecedented information				
·Determine if request for information (RFI)				
·Determine if information update				
Convert information to system format requirements				
·Detect present information format				
·Determine ability to use system information format				
Organize Information				
Determine Request Type				
·Establish if Mission Specific				
·Determine if Frequent Request				
·Classify as Administrative Request				
·Classify as Unknown Request Type				
Determine Urgency/Importance				
·Determine Date/Time of Request				
·Establish Classification				
·Classify as Unknown Urgency/Importance				
Filter Information				
Discard Information				
·Establish if Outside Request Timeline				
·Determine if Disreputable Source				
·Classify as Non-Mission Related				
·Determine if Erroneous Data				
Continue to Process Information				
·Prioritize Information Request				
·Tag Data				
Store Information				
Classify for Long-Term Data Storage				
Classify as Short-Term Data Storage				
Present/Display Information				
Produce Visual Display				
·Establish Textual Display				
·Determine Need for Pictorial Displays				
Produce Audio Display				
·Establish Sounds				
Distribute Information				
Determine Information to Push				
·Establish Receiving Unit				
·Determine if Response to RFI				
·Tag Data to Push				
Convert Data to Output Format				
Update Existing Information				
·Establish Information Sources to Update				
·Tag Data to Update				

Table 3. Requirements Traceability Matrix–Input Requirements

2. Requirements Traceability Matrix–Output Requirements

Functions	1.1.2. Output Requirements			
	1.1.2.1. The ISD system shall push data and information to the middle approach system (smart push/pull).	1.1.2.2. The ISD system shall provide updated, new, and/or corrected information to the bottom-up system.	1.1.2.3. The ISD system shall provide mission information to the user system.	1.1.2.4. The ISD system shall provide mission information to the side view system (disadvantaged user).
Collect/Gather Information				
Interact with external information systems				
·Pull information				
·Receive (pushed) information				
Distinguish information sharing format/communication protocols				
·Confirm information sharing protocols within specifications				
·Identify information sharing protocols outside specifications				
Process Information				
Categorize information				
·Determine if new/unprecedented information				
·Determine if request for information (RFI)				
·Determine if information update				
Convert information to system format requirements				
·Detect present information format				
·Determine ability to use system information format				
Organize Information				
Determine Request Type				
·Establish if Mission Specific				
·Determine if Frequent Request				
·Classify as Administrative Request				
·Classify as Unknown Request Type				
Determine Urgency/Importance				
·Determine Date/Time of Request				
·Establish Classification				
·Classify as Unknown Urgency/Importance				
Filter Information				
Discard Information				
·Establish if Outside Request Timeline				
·Determine if Disreputable Source				
·Classify as Non-Mission Related				
·Determine if Erroneous Data				
Continue to Process Information				
·Prioritize Information Request				
·Tag Data				
Store Information				
Classify for Long-Term Data Storage				
Classify as Short-Term Data Storage				
Present/Display Information				
Produce Visual Display				
·Establish Textual Display				
·Determine Need for Pictorial Displays				
Produce Audio Display				
·Establish Sounds				
Distribute Information	X	X	X	X
Determine Information to Push	X			
·Establish Receiving Unit	X	X	X	X
·Determine if Response to RFI	X	X	X	X
·Tag Data to Push	X			
Convert Data to Output Format	X	X	X	X
Update Existing Information		X		
·Establish Information Sources to Update		X		
·Tag Data to Update		X		

Table 4. Requirements Traceability Matrix–Output Requirements

3. Requirements Traceability Matrix–External Interface Requirements

Functions	1.2. External Interface Requirements			
	1.2.1. The ISD system shall interface with the bottom-up system.	1.2.2. The ISD system shall interface with the middle approach system (smart push/pull).	1.2.3. The ISD system shall interface with the user system.	1.2.4. The ISD system shall interface with the side view system (disadvantaged user).
Collect/Gather Information	X	X	X	X
Interact with external information systems	X	X	X	X
·Pull information	X	X	X	X
·Receive (pushed) information	X	X	X	X
Distinguish information sharing format/communication	X	X	X	X
·Confirm information sharing protocols within specifications	X	X	X	X
·Identify information sharing protocols outside specifications	X	X	X	X
Process Information				
Categorize information				
·Determine if new/unprecedented information				
·Determine if request for information (RFI)				
·Determine if information update				
Convert information to system format requirements				
·Detect present information format				
·Determine ability to use system information format				
Organize Information				
Determine Request Type				
·Establish if Mission Specific				
·Determine if Frequent Request				
·Classify as Administrative Request				
·Classify as Unknown Request Type				
Determine Urgency/Importance				
·Determine Date/Time of Request				
·Establish Classification				
·Classify as Unknown Urgency/Importance				
Filter Information				
Discard Information				
·Establish if Outside Request Timeline				
·Determine if Disreputable Source				
·Classify as Non-Mission Related				
·Determine if Erroneous Data				
Continue to Process Information				
·Prioritize Information Request				
·Tag Data				
Store Information				
Classify for Long-Term Data Storage				
Classify as Short-Term Data Storage				
Present/Display Information				
Produce Visual Display				
·Establish Textual Display				
·Determine Need for Pictorial Displays				
Produce Audio Display				
·Establish Sounds				
Distribute Information				
Determine Information to Push				
·Establish Receiving Unit				
·Determine if Response to RFI				
·Tag Data to Push				
Convert Data to Output Format				
Update Existing Information				
·Establish Information Sources to Update				
·Tag Data to Update				

Table 5. Requirements Traceability Matrix–External Interface Requirements

4. Requirements Traceability Matrix–System-wide Requirements

Functions	1.3. System-wide Requirements								
	1.3.1. The ISD system shall provide a means to connect information sources, enable collaboration, and promote information exchange to facilitate meeting mission requirements.	1.3.2. The ISD system shall be designed to promote accessibility to information based on the user need, mission, and purpose of information sharing and information discovery.	1.3.3. The ISD system shall be equipped with components that include a network backbone, software, and hardware necessary to process, receive, and provide information as defined by the user.	1.3.4. The ISD system shall organize raw data and information received in a logical format that promotes user-friendliness.	1.3.5. The ISD system shall continuously renew existing information with updated, new, and/or corrected so user(s) have access to the most current information.	1.3.6. The ISD system shall comply with the designated computer network and network infrastructure protocol.	1.3.7. The ISD system shall have and provide, when accessed, informal training for new users.	1.3.8. The ISD system shall comply with the designated communications protocols.	1.3.9. The ISD system shall ensure information confidentiality, integrity, and availability are preserved through use of security tools designated by the appropriate directives.
Collect/Gather Information					X				
Interact with external information systems					X				
·Pull information					X				
·Receive (pushed) information					X				
Distinguish information sharing format/communication protocols					X				
·Confirm information sharing protocols within specifications					X				
·Identify information sharing protocols outside specifications					X				
Process Information	X					X		X	
Categorize information	X					X		X	
·Determine if new/unprecedented information	X					X		X	
·Determine if request for information (RFI)	X					X		X	
·Determine if information update	X					X		X	
Convert information to system format requirements	X		X			X		X	
·Detect present information format	X		X			X		X	
·Determine ability to use system information format	X		X			X		X	
Organize Information	X			X					
Determine Request Type	X			X					
·Establish if Mission Specific	X			X					
·Determine if Frequent Request	X			X					
·Classify as Administrative Request	X			X					
·Classify as Unknown Request Type	X			X					
Determine Urgency/Importance	X			X					
·Determine Date/Time of Request	X			X					
·Establish Classification	X			X		X			
·Classify as Unknown Urgency/Importance	X			X					
Filter Information			X			X			X
Discard Information			X						X
·Establish if Outside Request Timeline			X						X
·Determine if Disreputable Source			X			X			X
·Classify as Non-Mission Related			X						X
·Determine if Erroneous Data			X						X
Continue to Process Information			X						X
·Prioritize Information Request			X						X
·Tag Data			X						X
Store Information			X		X				
Classify for Long-Term Data Storage			X						
Classify as Short-Term Data Storage			X						
Present/Display Information		X			X		X		
Produce Visual Display		X					X		
·Establish Textual Display		X					X		
·Determine Need for Pictorial Displays		X					X		
Produce Audio Display		X					X		
·Establish Sounds		X					X		
Distribute Information							X		
Determine Information to Push							X		
·Establish Receiving Unit							X		
·Determine if Response to RFI							X		
·Tag Data to Push							X		
Convert Data to Output Format							X		
Update Existing Information							X		
·Establish Information Sources to Update							X		
·Tag Data to Update							X		

Table 6. Requirements Traceability Matrix–System-wide Requirements

5. Requirements Traceability Matrix–Trade-off Requirements

Functions	1.4. Trade-off Requirements			
	1.4.1. The ISD system shall incorporate cost and performance as part of the tradeoff design.	1.4.2. The ISD system shall incorporate security, functionality, and quality as parts of the performance tradeoff design.	1.4.3. The ISD system shall incorporate development, maintenance, and other life cycle costs (such as operations and support and system disposal) as parts of the cost tradeoff design.	1.4.4. The ISD system shall incorporate bandwidth, infrastructure support, network strength, technological advances, and environment as part of the overall system tradeoff design.
Collect/Gather Information	X			X
Interact with external information systems	X			X
·Pull information	X			X
·Receive (pushed) information	X			X
Distinguish information sharing format/communication protocols	X			X
·Confirm information sharing protocols within specifications	X			X
·Identify information sharing protocols outside specifications	X			X
Process Information	X		X	X
Categorize information	X		X	X
·Determine if new/unprecedented information	X		X	X
·Determine if request for information (RFI)	X		X	X
·Determine if information update	X		X	X
Convert information to system format requirements	X		X	X
·Detect present information format	X		X	X
·Determine ability to use system information format	X		X	X
Organize Information				
Determine Request Type				
·Establish if Mission Specific				
·Determine if Frequent Request				
·Classify as Administrative Request				
·Classify as Unknown Request Type				
Determine Urgency/Importance		X		
·Determine Date/Time of Request				
·Establish Classification				
·Classify as Unknown Urgency/Importance				
Filter Information		X		
Discard Information		X		
·Establish if Outside Request Timeline		X		
·Determine if Disreputable Source		X		
·Classify as Non-Mission Related		X		
·Determine if Erroneous Data		X		
Continue to Process Information		X		
·Prioritize Information Request		X		
·Tag Data		X		
Store Information				
Classify for Long-Term Data Storage				
Classify as Short-Term Data Storage				
Present/Display Information		X		X
Produce Visual Display		X		X
·Establish Textual Display		X		X
·Determine Need for Pictorial Displays		X		X
Produce Audio Display		X		X
·Establish Sounds		X		X
Distribute Information				
Determine Information to Push				
·Establish Receiving Unit				
·Determine if Response to RFI				
·Tag Data to Push				
Convert Data to Output Format				
Update Existing Information				
·Establish Information Sources to Update				
·Tag Data to Update				

Table 7. Requirements Traceability Matrix–Trade-off Requirements

6. Requirements Traceability Matrix–Qualification Requirements

Functions	1.5. Qualification Requirements			
	1.5.1. The qualification system for the ISD system shall prove information sharing and information discovery pertinent to the mission.	1.5.2. The qualification system for the ISD system shall prove accessibility for COIs seeking to mission critical information.	1.5.3. The qualification system for the ISD system shall prove that COIs will dictate information discovery.	1.5.4. The qualification system for the ISD system shall prove value to the NCOW mission.
Collect/Gather Information				
Interact with external information systems				
·Pull information				
·Receive (pushed) information				
Distinguish information sharing format/communication protocols				X
·Confirm information sharing protocols within specifications				X
·Identify information sharing protocols outside specifications				X
Process Information	X			
Categorize information	X			
·Determine if new/unprecedented information				
·Determine if request for information (RFI)				
·Determine if information update				
Convert information to system format requirements				X
·Detect present information format				X
·Determine ability to use system information format				X
Organize Information		X		
Determine Request Type		X		
·Establish if Mission Specific				
·Determine if Frequent Request				
·Classify as Administrative Request				
·Classify as Unknown Request Type				
Determine Urgency/Importance		X		
·Determine Date/Time of Request				
·Establish Classification				
·Classify as Unknown Urgency/Importance				
Filter Information				
Discard Information				
·Establish if Outside Request Timeline				
·Determine if Disreputable Source				
·Classify as Non-Mission Related				
·Determine if Erroneous Data				
Continue to Process Information		X		
·Prioritize Information Request				
·Tag Data				
Store Information				
Classify for Long-Term Data Storage				
Classify as Short-Term Data Storage				
Present/Display Information		X		
Produce Visual Display				
·Establish Textual Display				
·Determine Need for Pictorial Displays				
Produce Audio Display				
·Establish Sounds				
Distribute Information			X	
Determine Information to Push				
·Establish Receiving Unit				
·Determine if Response to RFI				
·Tag Data to Push				
Convert Data to Output Format				
Update Existing Information			X	
·Establish Information Sources to Update			X	
·Tag Data to Update			X	

Table 8. Requirements Traceability Matrix–Qualification Requirements

This chapter summarized and presented key products created in the process of developing a functional architecture for the ISD system. The reasons behind the need to develop a functional architecture of a system were discussed and functions were identified for the ISD system. An ISD system functional hierarchy was presented,

followed by ISD system functional decompositions. The last section introduced a requirements traceability matrix to aid in tracing requirements to elements of the ISD system's functional architecture.

The final chapter of this thesis will provide a research summary and present the conclusions of this study.

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VI. CONCLUSIONS AND FUTURE RESEARCH

Research is to see what everybody else has seen, and to think what nobody else has thought.
- Albert Szent-Gyorgyi

This chapter summarizes the research conducted throughout the course of this thesis. The need for information sharing and discovery systems is re-iterated because information plays an important role in today's military environment. Key points for recommendation are also introduced to highlight potential areas for further research.

A. RESEARCH SUMMARY

To meet the challenges of the Information Age, the DoD needs to employ systems that are able to share and discover critical information to COIs efficiently. These systems—information sharing and discovery systems—are crucial to military operations because our strategic plans are only as good as the information that it is composed of. Likewise, information sharing and discovery are a central element in missions that employ network-centric operations and warfare, so it is imperative that the DoD is able to design and acquire ISD systems efficiently.

The problem exists that there is currently no specific guidance that identifies what ISD systems entail. There is an absence of basic elements of the systems engineering approach and design for ISD systems, such as: an operational concept; requirements; interface guidance; and functional architecture. Therefore, it is often hard for a user to understand what an ISD system should be comprised of. It is even more difficult for DoD acquisition professionals to acquire or develop ISD systems because of the lack of systems design requirements.

Chapter I of this thesis discussed the background and personal motivation of the study. The purpose, research questions, benefits of the study, scope, and methodology of the thesis were explored.

Chapter II reviewed the history of network centric operations and the network centric warfare model and it's applications to current military doctrine. These concepts

were summarized to highlight the importance of information sharing and information discovery to ongoing military strategic planning.

Chapter III introduced the concepts of information sharing and information discovery, and defined these terms as the basis of this study. A survey of current DoD ISD systems was conducted to give the audience examples of services available to warfighters presently. This chapter also discussed emerging industry trends for ISD systems and assessed their applicability to the DoD.

Chapter IV used a systems engineering approach to refine the operational concept of ISD systems and derive requirements for future acquisitions of ISD systems. This chapter also analyzed the interactions that ISD systems have with external systems, and discussed the importance of clear objectives during the conceptual phase.

Chapter V used a systems engineering design approach to establish a functional architecture for the ISD system. This chapter discussed the functions identified for the ISD system and presented the ISD system functional hierarchy.

This chapter (VI) concludes the thesis by summarizing key points made throughout the study. This chapter also suggests several areas to conduct further research about ISD systems.

B. KEY POINTS OF THE STUDY

This thesis was built upon Goshorn's network-centric top-down approach (Figure 11), to demonstrate the elements of the ISD system. ISD systems include the information sharing platform, which is made from an abundance of Web-enabled tools and services such as: wikis; blogs; Web portals; search engines; enterprise services; and collaborative technologies. These tools form the foundation, or the information structure, for information sharing to occur. Subsequently, using systems within the information sharing domain enable COIs to discover information that is relevant to their mission. Information discovery enables COIs to take action to advance their mission objectives and overall effectiveness. Figure 12 was central to this study as it presented a generalized model based on the (four) network-centric approaches and explained how information

sharing leads to information discovery in an ISD system. This ISD system model was used to examine several current ISDs, and forms the basis of the system architecture presented in Chapters IV and V.

Having established the basis of ISD systems, and after exploring the definition of information sharing and information discovery, this study applied the systems engineering process to the design of ISD systems. Several key elements of the systems engineering approach were introduced for ISD systems. An operational concept was refined, requirements were generated, and a basic functional architecture was presented.

C. AREAS FOR FURTHER RESEARCH

There are numerous areas that can be researched to further enhance this thesis. The bulk of these are found in Chapter III's exploration of ISD tools currently in use by the DoD and relevant ISD industry trends. Time constraints and the scope of this thesis permitted only a survey of these systems, but any of the topics under these sub-sections can be investigated with more detail.

This thesis applied the systems engineering approach to a generalized ISD system, and presented a template of factors to consider when designing a real ISD system. This was organized in this manner with the understanding that this thesis would be used as a basis for guidance during the acquisition of an actual ISD system. Further research can be conducted on ISD systems with specific objectives and for detailed warfare missions (i.e., Maritime Domain Awareness, Undersea Warfare, Anti-Submarine Warfare).

D. FINAL SUMMARY

Information is a key component to successful military planning and operations because it produces knowledge and enables action to occur. Therefore, today's military professional requires current, relevant, and credible information to be able to sustain the transforming warfare environment. This is not a simple task in the modern national defense setting. The advent of information technologies, and the abundance of information, has introduced an entirely new set of conditions that must be met in order to remain competitive against our adversaries. With this in mind, it is imperative that the

DoD is able to acquire ISD systems that are capable of sustaining the military through the Information Age and into the next revolutionary era. National defense requires that we not only keep abreast of the dynamic world we live in, but that we are also able to see the entire context of the problem (or system).

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